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Tropical Cloud System and Processes (TCSP)

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Near-realtime Ground Validation of Satellite Precipitation Retrievals for TCSP and GPM

by

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Proposal Summary

Near-realtime ground validation of satellite retrieval products represents a long-sought capability by NASA, but for a few momentary exceptions, a capability not yet realized. The research program offered here will develop a near-realtime ground validation capability for space-based precipitation remote sensing, in general, and for space-based precipitation remote sensing in support of NASA's cloud-centric Tropical Cloud System and Processes (TCSP) field campaign, in particular. The central objective of the proposed research is to develop a rapid turn-around (near-realtime) ground validation capability for frequently-reported satellite precipitation products, and then testing this capability for scientific purposes during the TCSP field phase. The foremost validation capabilities will be as follows: (1) defining error (uncertainty) characteristics of instantaneous/high spatial resolution/high frequency sampled rain retrievals from a Passive-Microwave/Geostationary-Infrared blended satellite rainrate product data stream, (2) detecting and eliminating instances of significant (serious) flaws in instantaneous retrievals, and (3) delivering this information in terms of well-defined error metrics back to scientific participants.

This capability has never been adequately developed for precipitation retrieval, either in an engineering sense (i.e., in the design of an effective data acquisition and communications system), or more importantly in a scientific-methodological sense (i.e., in the design of effective measuring, statistical, mathematical, and algorithmic tools applicable for end user scientific needs). This project will develop and test both a methodology and an engineering approach for this purpose in support of the NASA TCSP field phase, as well as for other specialized and standardized applications which will arise in the future -- the most relevant of these being the end-of-decade Global Precipitation Measurement (GPM) Mission under development by NASA and its major international partners, i.e., the Japan Aerospace Exploration Agency (JAXA) and the European Space Agency (ESA). The main scientific objective of the research, in the context of the TCSP research program, is to demonstrate a quantification of the error-of-estimate property of the large scale satellite precipitation field immediately prior to and during the course of relevant TCSP field phase aircraft (A/C) missions (in order to support A/C mission science), and in-the-field scientific decision making. At the larger scale and for the longer term, vis-à-vis the GPM Mission and its supporting field campaigns, the principal scientific objective is to develop the near-realtime GV capability for improving rainfall data assimilation in global and limited area numerical weather prediction models using GPM rain retrievals. Optimized data assimilation of rainfall data requires detailed, quantitative information concerning surface rainfall bias and conditional bias uncertainty, as well as spatial error covariance (both horizontal and vertical) of the retrieved rainrate estimates -- to maximize the impact of continuous rainfall data assimilation in the course of a forecast.

In summary, developing and testing a near-realtime capability in the TCSP experimental framework is an ideal means for ensuring an effective, near-realtime ground validation system for GPM in the future. As a cloud-oriented study, the TCSP field campaign will profit from well-understood remotely sensed estimates of space-based precipitation over the large scale (including views beyond the coastal radar systems supporting TCSP). Furthermore, the research will produce a prototype of the kind of validation system that will be needed by the GPM Mission's retrieval program and its various supporting and related field campaigns.

1.0 Science Plan

1.1 Introduction and Background

Confirming the reliability and defining estimate uncertainties in satellite retrievals of precipitation on a timely basis represents a scientifically attractive capability for NASA's specialized and systematic observational programs involving such retrievals, but a capability yet to emerge in either an engineering sense, or more importantly in a scientific sense. In terms of field campaigns examining the microphysical and life cycle properties of clouds, a near-realtime ground validation (GV) capability would be extremely useful for flight planning and identifying problem areas of clouds related to precipitation retrieval itself. In considering precipitation-focused NASA space missions, such a capability is now deemed essential for purposes of optimized data assimilation at experimental and operational weather forecast centers (Smith et al., 2004a). The proposed research addresses both of these issues in the context of the Tropical Cloud Systems and Processes (TCSP) research program by using the TCSP field campaign setting to help develop and test a near-realtime GV capability, and then using the tested / refined system as a prototype for the end-of-decade Global Precipitation Measurement (GPM) Mission.

In the course of cloud-centric field campaigns it is always desirable to be up-to-date on all aspects of the cloud observational palette under study, with the TCSP experiment being no exception. A primary cloud variable is the temporally and spatially changing precipitation structure, particularly in the case of tropical storms and cyclones -- which is a main focus of TCSP research. The history of earth science within NASA has taught the lesson that cloud-focused experiments fare best when the cloud structure variable is acquired across the large scale experimental domain from a satellite perspective, which with an intelligent blend of satellite resources can now be done consistently, continuously, and effectively. Insofar as the precipitation field, a number of near realtime precipitation data products based on blends of passive microwave (PMW) measurements and geostationary satellite infrared measurements (GEO-IR) are now available on line (Janowiak 2004).

An equally important but perhaps more subtle issue is defining the principal error properties of the precipitation estimates. Satellite radiometers, and in the case of the Tropical Rainfall Measuring Mission (TRMM) satellite, the Precipitation Radar (PR), are excellent instruments to obtain the large scale observed rain field (Smith and Hollis 2002). However, as a number of studies based on TRMM rain retrievals, and retrievals from other PMW radiometers have found (such as from SSM/I radiometers on DMSP satellites and from the AMSR-E radiometer on the AQUA satellite), satellite retrievals are prone to significant random errors, albeit on an infrequent basis. The ultimate source of these errors is almost always the lack of heterogeneous cloud optics over the relatively large radiometer and/or radar beams, whose *average* beam properties must be used as inputs to algorithms which formulate non-linear relationships between measured microwave energy (either emitted passively or reflected actively) and rainrate -- the so-called heterogeneous beam-filling problem. [In more general terms, this is the classic scaling problem in which the transform of an average is not equivalent to an average of the transform in a non-linear system.]

Moreover, satellite retrievals generally contain some type of systematic offset or multiplicative bias (or both), factors that are inevitability known only to a certain degree of certainty (i.e., the problem of bias uncertainty, which is generally conditional with respect to rainrate). Therefore, whenever conducting research with satellite precipitation retrievals, there are underlying uncertainties, and more often than not, the success of the research is predicated upon knowing the uncertainties at the same time the precipitation retrievals are arriving on the scene. Thus, during field campaigns or data assimilation-driven weather forecast scenarios where near-realtime data delivery is considered essential, the retrieval error characteristics and GV information can only produce value at the same data latencies as the rain retrievals themselves. It is from this perspective that the proposed research is motivated. That is, initially the TCSP observational program can and should make use of a near-realtime GV capability to acquire satellite precipitation information to assist in scientific decision making in conducting aircraft (A/C) flight planning and/or defining ground radar processor strategies -- where the meaning of precipitation information should be considered as the combination of both rainrate retrievals and independent retrieval error properties. A near-realtime GV capability can also enable timely decision making during A/C storm reconnaissance, helpful both for in-flight track adjustments and to some extent for ensuring safe A/C procedures. Near-realtime GV also provides a means for downstream flight planning in conjunction with tropical storm and cyclone zones where particular problems arise insofar as retrieval error. Finally, the TCSP process, experience, and testing should be used to design and refine the GPM Mission's prototype near-realtime GV system in the context of both data assimilation and field campaign support.

Notably, the TRMM GV research program has now produced results at three of its main radar-based GV sites that have demonstrated how research-quality radar data can be used to prescribe standard independent error metrics to satellite retrievals, as well as offering evidence that serious instantaneous satellite retrieval errors can be identified autonomously. The relevant methods and selected results have been described by Wolff (2003, 2004) and Smith (2004), available on line. In addition, preliminary results and parts of the methodology description are now in a refereed journal manuscript under review (Wolff et al. 2004).

The GPM Mission represents a flagship international research program designed to better address: (1) global water and energy cycle issues involving space-time variations in rainfall accumulations and how they affect climate change and its consequences, (2) the need for advanced satellite data assimilation systems for improving weather forecasting, and (3) better surface rainfall data inputs for hydrometeorological predictions applied to such problems as flood or drought forecasting and fresh water resource assessment. The primary advantage of the GPM Mission is that it can extend the TRMM rainfall time series while making substantial improvements in space-based precipitation observations, specifically in terms of measurement accuracy, dynamic range, sampling frequency, spatial coverage, and spatial resolution. In order to achieve this goal, the GPM Mission is designed as a constellation of low earth orbiting satellites carrying passive and active microwave measuring instruments (Smith et al. 2004a). One of these satellites is being developed along the lines of the TRMM satellite (referred to as the GPM Core satellite), carrying an instrument suite consisting of a dual frequency Ku/Ka-band radar (DPR), and a conical-scanning, multichannel-polarimetric PMW radiometer (GMI). Additional satellites in the international, partner-based constellation will carry a variety of multi-channel microwave radiometers with appropriate rain-detecting frequencies (e.g., Mugnai et al. 2004). Whereas the orbit and instruments on these constellation satellites will vary, each of them will have to meet a minimum standard insofar as rain retrieval.

To ensure measurement standards, an integral part of the GPM mission will be an international GV program which will define the accuracy, precision, and overall quality of rain products derived from the multiple satellites and instruments (Smith et al. 2004b). There is already a well-established GV program to assess TRMM satellite precipitation products (Marks et al. 2000). This program includes four primary ground sites set-up with one or more radar systems and rain gauge networks. The primary goal of the TRMM GV program is to produce quality-controlled radar products to generate monthly, gauge-adjusted rainfall at these sites. [These products are found on NASA's TRMM GV website.] They include monthly GV products and associated statistics, along with comparisons between daily/monthly probability distribution function (pdf) information from the PR and coincident ground-based radar data. However, the TRMM GV program does not include any type of capability for near-realtime quantitative validation of satellite precipitation in terms of space-time error characterization or serious error detection in the instantaneous retrievals. By the same token, this capability is now considered a Level 1 requirement for GPM's GV research program.

Within the framework of the GPM Mission, the space-time error characterization of retrieved rainrates is important and necessary for: (1) rainrate data assimilation in weather prediction and hydrometeorological modeling, (2) detection and verification of statistically significant trends and variations in rainfall time series, and (3) supporting scientific decision making in supporting or related field campaigns -- these issues are discussed in the GPM draft Level 2 GV requirements document (Smith and Everett 2004) and Bidwell et al. (2004). Therefore, one of the main scientific objectives of the GPM GV program is to ascertain the quality of satellite rainrate products in terms of error characterization metrics, and to detect and understand the causes of serious errors within the instantaneous rainrates themselves (Bidwell et al. 2003). Error characterization is also crucial for assessing the performance of satellite rainrate retrieval algorithms, enabling refinement of: (1) the algorithms, (2) the underlying cloud models, and (3) the microwave radiative transfer models used in the retrieval algorithms.

To achieve these goals, the GPM GV program is planning two sub-programs: (1) a Routine Product Site Program (RPSP), and (2) a Focused Observational Program (FOP). While the FOP will be a mix of research experiments with varying scientific goals, the RPSP will provide near-realtime GV products derived from ground-based instruments (including Doppler/polarimetric radars and/or Doppler/dual-frequency radars -- plus ground radiometers equipped with frequency diversity corresponding to that of the GMI on the GPM Core satellite). The RPSP program will involve a network of GV Supersites distributed around the globe representing different climate regimes (see Smith 2004). RPSP products will be crucial in defining uncertainty information for the error characterization of the GPM satellite products. NASA will provide two of these sites, while international partners will provide 5-6 additional sites (Smith et al. 2004b).

The scientific objectives of the present study include developing the measuring, statistical, mathematical, and algorithmic tools needed to define the essential error characterization quantities for RPSP-type sites, including TCSP radar sites, as well as detecting and reporting serious errors in instantaneous precipitation retrievals. The TCSP observational capability will include the deployment of the NASA NPOL radar (an S-band polarimetric system), augmented with the TOGA radar possibly deployed on a rented ship (Doppler C-band system with 1.65 deg beam). [We are aware of at least four proposals being submitted to the TCSP NRA which will require the availability of the NPOL radar, those of (1) Drs. Ali Tokay and Larry Carey at

NASA-GSFC/TAMU-MET, (2) Drs. Steven Nesbitt, Robert Cifelli, and Larry Carey (CSU-ATMOS/TAMU-MET), (3) Drs. Paul Kucera and Thomas Rickenbach (UND-ATMOS/NASA-GSFC), and (4) Dr. Jian-Jian Wang (JCET/NASA-GSFC). To date, we have conducted exchanges with investigators of the first two proposals concerning cooperation and coordination vis-à-vis NPOL data -- were either of these proposals to be awarded along with this proposal.]

In developing the methods and procedures for the near-realtime GV capability, we will use simulated GPM satellite precipitation products in conjunction with actual GV precipitation products from sites conforming to the RPSP standard. For purpose of the simulated GPM rainrates, we will use a current mixed PMW / GEO-IR satellite product developed by the TRMM project, i.e., blended algorithm 3b42 (Huffman et al. 2001), and a multi-satellite blended product available from the Naval Research Laboratory (NRL) in Monterey, CA (Turk et al. 1999, 2004). The former is a 3-hour product, the latter a variable time-step product which can be set to 30-minute or hourly for the duration of TCSP (J. Turk, personal communication, 2004).

We intend to use two existing RPSP-quality GV sites targeted for use by GPM to initially develop the procedures and required scientific software and to enable immediate progress on the development and testing elements of the research, once the TCSP program commences. These sites consist of: (1) the TRMM GV site in east-central Florida at Melbourne, and (2) the METEOCAT/UPC-GRAHI site in the Catalonia region of Spain, operated by the Regional Weather Service of Catalunya in Barcelona (METEOCAT), and their partner organization at the Group of Applied Research in Hydrometeorology of the Universitat Politecnica de Catalunya (UPC-GRAHI). Each of these sites is equipped with research-quality radar capability: (1) Melbourne with a Doppler S-band WSR-88D system -- which continuously supports the TRMM GV program, and (2) Catalonia with a 4-member Doppler C-band network system -- which has committed itself to operating as a GPM GV Supersite (Paricio 2004). In addition, each of these sites is equipped with a densely distributed raingauge network and sufficient disdrometer capability to support radar calibration procedures.

1.2 Specific Scientific Objectives

(1) Develop and implement GV techniques, methodologies, and procedures on two current GV sites (TRMM-Melbourne and Catalonia-METEOCAT/UPC-GRAHI) necessary to achieve preliminary, near-realtime capability that addresses main requirements for RPSP-type GPM GV site, i.e.: (a) GV precipitation product generation, (b) rainrate retrieval error characterization, (c) detection and filtering of substantive (serious) instantaneous precipitation retrieval errors, and (d) near-realtime GV data transfer and final archiving vis-à-vis GPM data handling protocols.

(2) apply quantitative error characterization and error detection/filtering procedures on ongoing GPM-like precipitation retrievals (TRMM algorithm 3b42 and NRL-Monterey blended satellite product) within TCSP experiment domain under cover (section 2.1) and beyond cover (section 2.3) of research radars deployed for TCSP support, i.e., NASA's NPOL and TOGA radars [1], using TCSP testing process as means to develop GPM's prototype near-realtime GV system.

[1] There is also a possibility that the NOAA K-band profiler will be deployed by Dr. Sergey Matrosov of NOAA-ETL (Boulder, CO), based on his proposal to the TCSP NRA.

2.0 Research Plan

2.1 Description of Required Datasets

2.1.1 GPM-Simulated Satellite Precipitation Data Sources

As noted earlier, the frequently-sampled satellite retrievals we intend to use for simulating GPM rainrates are from: (1) TRMM standard algorithm 3b42 (a blended product), and (2) the NRL-Monterey multi-satellite PMW/GEO-IR blended product.

The NRL algorithm is designed as a realtime rainrate product based upon blending GEO-IR estimates from operational geostationary satellites and PMW estimates from currently available PMW instruments, e.g., TMI, SSM/I, AMSR-E, AMSU, and WINDSAT. The sampling frequency and spatial resolution of this algorithm are adjustable from 30-min and upward, and 10-km and upward. The basic methodology (Turk et al. 1999, 2004) is to use the PMW rainrate estimates based on the NOAA PMW operational algorithm to provide probability matching method (PMM) based rules for IR-EBBT to PMW rainrate transformations on a continuous basis, updated within localized and proximate space-time windows that keep the PMW and IR information in close contact. Its current configuration draws from a 9-member satellite constellation that includes PMW measurements from: (1) the TRMM Microwave Imager (TMI) instrument, (2-3) two DMSP Special Sensor Microwave Imager (SSM/I) instruments, (4) one NOAA-LEO Advanced Microwave Sounding Unit-B (AMSU-B) instrument, (5) the EOS-AQUA Advanced Microwave Scanning Radiometer (AMSR-E) instrument, and (6-9) IR measurements from two operational GOES, one operational METEOSAT, and one operational GMS imagers.

The TRMM 3b42 algorithm produces a half-degree blended gridded product that contains rainrates from TRMM estimates, SSM/I estimates, and GEO-IR estimates in which the TRMM estimates serve as the calibration reference. This algorithm now produces rainrates at a 3-hourly interval -- which will continue even after the decommissioning of the TRMM satellite (likely to take place during the summer of 2004).

A general description of the blending technique is as follows. Geostationary IR-EBBTs are first averaged to the approximate resolution of the PMW rainrate estimates. Each PMW-derived rainrate pixel is then paired with its corresponding EBBT (T_B), within a small time window (e.g., 15-minute) and within a small distance (e.g., 10-km). For each collocated dataset in a surrounding grid box (e.g., 2.5 deg scale), the pdf histograms of IR brightness temperatures and PMW rainrates are matched in the form of a PMM relationship (Calheiros and Zawadski 1987; Rosenfeld et al. 1995; Grose et al 2002), that is a T_B-rainrate lookup table is created. To maintain the rain history, the histograms of these coincident data are accumulated until the PMW coverage of a specified grid box (say 2.5 deg) exceeds a specified coverage threshold (say 90%). The more frequently arriving geostationary data are then converted to rainrates by using the look-up table. To ensure spatial smoothness in the data, the rainrate in each grid box is found by using an inverse-distance weighted average of say eight nearest lookup table-derived rainrates surrounding the grid box. In addition, for the NRL algorithm, 850 hPa wind vectors from the Navy Operational Global Atmospheric Prediction System (NOGAPS) forecast model are analyzed against a 2-minute resolution topographic database, which is applied in regions of likely orographic effects (Vicente et. al 2002). Finally, the IR brightness temperature history in the previous time window, say 30-min, can be analyzed for regions of active cloud top temperature growth or decay, with scaling factors applied to intensify or weaken the overall rainrate based on growth or decay rates.

Rainfall accumulations are then updated to produce final products at typically 1- to 3-hour intervals. In general, these estimates should be validated against surface raingauge measurements or research-quality radar rainrate estimates.

2.1.2 Ground Validation Data Sources

TRMM/GPM Sites

As noted earlier, data from two current research-quality GV sites, i.e., Central Florida and Catalonia METEOCAT/UPC-GRAHI are to be used to initially develop the near-realtime GV program requirements. These sites have been chosen on the basis of their well-established, high quality radar measurements, their densely distributed raingauge networks, and their diversity in sampling contrasting precipitation regimes (seasonally tropical vs. seasonally semi-arid) -- in which both experience severe convective storms in summer and winter. Moreover, as described later, precipitation at these sites result from diverse local and large-scale, dynamical and physical processes, providing a variety of test cases for the GV research. Also, these sites are models for the international GPM GV Supersite program, providing an immediate opportunity (without waiting for the TCSP field phase to commence) to develop site-specific software modules needed for the physical validation process and the necessary data transfer procedures.

TCSP Sites

For TCSP applications, we will use the NASA NPOL and TOGA radar facilities to be deployed in some time of intersection arrangement, likely in the western portion of Costa Rica in proximity to the Pacific Ocean coast (with the possibility that the TOGA radar will be mounted on a ship). Whereas, the GV training from the Florida and Catalonia radars will be transmitted in near-realtime to GSFC for merging and processing with the simulated GPM satellite data, for the TCSP field campaign, we will transmit the satellite data to the NPOL radar processing facility in Costa Rica, onto a dedicated computer server which will receive the NPOL and TOGA data on-site for processing and analysis -- also on-site. [This setup eliminates problems in establishing dependable data communication links for the radar data to GSFC.] We are coordinating these facilities issues with Dr. John Gerlach, of GSFC's Wallops Island Radar Facility, who will serve as NASA's NPOL and TOGA radar operations leader during the TCSP field phase.

We are familiar with signal problems that will occur with the NPOL radar, because its back lobe source has never been physically characterized, and in addition, it suffers a spurious dipole source when its mesh antenna becomes wet. Although we have no solutions on hand to mitigate these problems with the NPOL data, we intend to develop and acquire partial solutions to lesson these problems during the course of TCSP. First of all, Mr. Wolff has considerable experience with the NPOL data that has been acquired for the TRMM GV project and has developed some untested ideas on how to overcome at least part of the signal contamination due to the two signal problems. Moreover, a small team of scientists from NASA's Precipitation Measurement Missions Science Team involved with the West African AMMA experiment, working with Dr. Gerlach and also in consultation with Prof. Chandrasekar at Colorado State University, is planning to study various physical and empirical methods to mitigate NPOL signal problems, noting there is a good possibility that NPOL will be deployed for the 2006 AMMA season. Although we expect these problems to arise in the course of our research, we see no particular reason to hesitate from seeking solutions to these problems both with our team and with other colleagues.

Central Florida TRMM Site

The Central Florida site is centered around the Melbourne-Florida WSR-88D radar, located on the eastern U.S. Atlantic coast. The radar is complemented by several raingauge networks, including a NASA-sponsored network at Kennedy Space Center (KSC), and several state-sponsored Water Management District (WMD) networks (Southwest Florida WMD, St. John's River WMD, and South Florida WMD).

The local topography includes the savannah upland portion of the eastern coast of central Florida surrounding Melbourne. The Florida peninsula is relatively flat. Lake Okeechobee is located to the southeast with the Atlantic Ocean occupying the northeast and southeast quadrants of the radar domain. Anomalous propagation (AP) is regular feature over land in the northwest and southwest quadrants and is more prevalent during the late evening and early morning hours. Clear air echoes are enhanced during dry periods and along density-driven boundaries (e.g., sea breeze, land breeze, fronts, dry lines). Precipitation in this area is dominated by two principal mechanisms: (1) small scale isolated convective systems initiated by sea-breeze/land-breeze discontinuities, and (2) organized tropical storms/easterly waves. The tropical storm season begins in June and runs throughout November, with the intensity and frequency of tropical storms at their highest during the later summer months of August and September. A substantive portion of Florida's annual rainfall is also accounted for by mid-latitude synoptic systems during the northern hemispheric winter months.

The principal TRMM GV radar is located in Melbourne at a lat-lon coordinate of 28.11°N / 80.65°W. Figure 1 illustrates a map of the Melbourne site, indicating the location of the radar with respect to the raingauges. Standard WSR-88D radar systems run in one of four modes. There are two clear air modes, which provide enhanced sensitivity for detection of spurious reflectors such as birds, insects, and air density differences (e.g., sea breeze fronts). The clear air modes provide only 4 low-level tilts. Once rain is detected, the radar is switched to precipitation mode for which there are two sub-modes: (1) a 9-tilt volume-scan (VOS), and (2) a 14-tilt VOS referred to as the severe weather mode (SWM). In conjunction with the WSR-88D Operational Support Facility (OSF) and the Melbourne National Weather Service Office (NWSO), under agreement with NASA/GSFC, the Melbourne radar is operated in SWM whenever precipitation is present. Table 1 provides a description of the Volume Coverage Pattern (VCP) for the WSR-88D radar (Crum et al. 1993).

All of the Melbourne WSR-88D radar data are currently being received at NASA/GSFC in near-realtime via the Collaborative Radar Acquisitions Field Test (CRAFT) system. The latency for the radar data is on the order of 5-10 minutes from the time of observation. The data are archived routinely by the GSFC TRMM Office and are routinely converted to Universal Format (UF) for distribution to interested scientists.

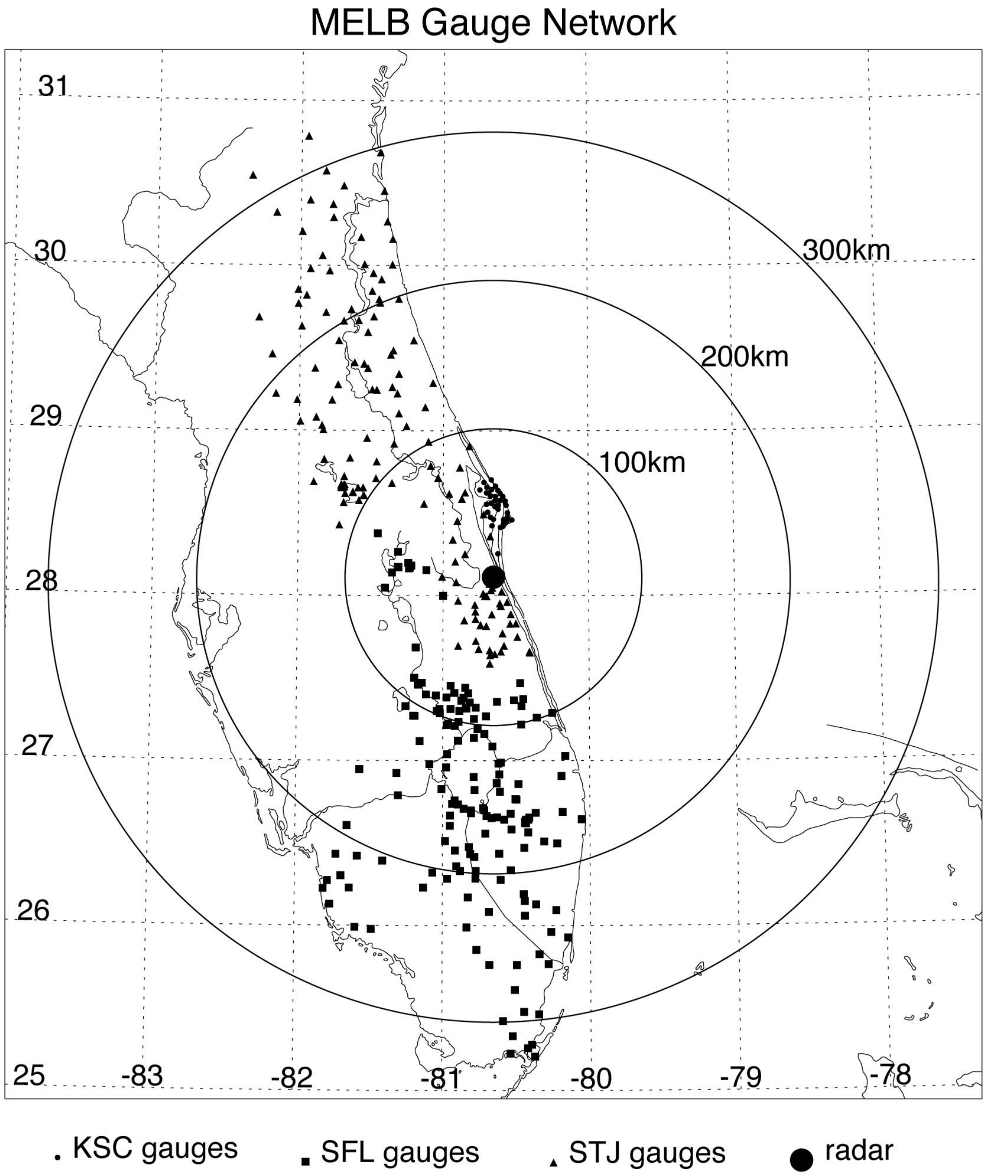

Figure 1: Map of Melbourne, Florida TRMM/GPM GV site.

Table 1: Number of raingauges available in various gauge networks over central Florida. Florida's Water Management District (WMD) gauges are operated by associated state-sponsored offices, while remaining networks are operated by NASA/GSFC.

GV SITE	Gauge Network	No. Gauge Sites	Gauge Type	Rain Increment (mm)
Melbourne	St. Johns WMD	27	Tipping Bucket	0.254
	Kennedy Space Center	33	Tipping Bucket	0.254
	South Florida WMD	129	Tipping Bucket	0.254
	Triple-N Ranch	20	Tipping Bucket	0.254

In addition to the radar data, there are three principal raingauge networks supporting the Melbourne GV program: (1) Kennedy Space Center (KSC), (2) St. John's River Water Management District (STJ), and (3) the South Florida Water Management District (SFL). [These acronyms match those used in Fig. 1.] Additionally, a high-density raingauge network (DRGN) was installed prior to a 1998 TRMM-supported field campaign (TEFLUN-B) to provide validation of ground radar rainfall estimates. There is a total of ~200 gauges for all 3 networks.

The KSC gauge network consists of 33 tipping bucket rain gauges. Most of these sites are distributed across the Cape Canaveral peninsula and report time-of-tip via telemetry. Problems occurring with individual sites are logged and reported. The TRMM Satellite Validation Office (TSVO) receives data each month via File Transfer Protocol (FTP). This system of data retrieval has performed well since the launch of TRMM satellite with only a few miscellaneous problems reported. An on-site NASA contractor handles maintenance concerns that arise, while laboratory calibrations are done at least once a year. KSC is the only network in Florida for which the TSVO Office supplies equipment.

The STJ gauge network consists of 27 core sites (the number can vary slightly). These sites represent a subset of the total STJ gauge network, which covers a region that extends well beyond 200 km from the Melbourne radar. The region of coverage includes coastal locations around Melbourne and north of Cape Canaveral, and some sites in and around central Florida.

Data are sent to TSVO as a single file on a weekly basis using an automated FTP routine. One problem with the STJ data is that some sites tend to record multiple tips from time to time, which presents logistical problems when converting raw tip data into rainrates. Although a few of these suspect rainrates are not caught in the filter, the conversion algorithm ensures that rainfall totals in the derived rainrate data match those from the accumulated tip data.

The SFL raingauge network consists of ~129 sites that record rainfall every five minutes. The total number of sites can vary slightly from month-to-month due to the addition of new sites and removal of old sites, but these changes are accounted for, and overall, the number does not change significantly over time. The region of coverage includes the southern and central regions of Florida. Data are retrieved by TSVO using a database account provided by a cooperative agreement between NASA and the South Florida WMD. Although temporal resolution is coarser than ideally desired, the system has performed well with no interruptions in data access.

The TEFLUN-B DRGN consists of 20 gauges deployed on public land west of the Melbourne radar in central Florida. All gauges are located within an ~10 km^2 area. Data from this gauge network are routinely used to provide independent validation of ground radar rainfall estimates.

For purposes of this research, data from the Melbourne WSR-88D radar will be processed using the existing TRMM Ground Validation System (Marks et al. 2000) to produce Level I and II products. Figure 2 provides a flowchart depiction of the processing system. TRMM Science Products 2a53 (rain intensity), 2a54 (rain type), and 2a55 (three-dimensional gridded reflectivity) will be used. Table 2 provides a detailed description of these products. The system is generally automated, however, the quality control of the reflectivity data does require some manual intervention when AP or other anomalous non-meteorological echoes are present. An earlier configuration of this system is described in detail by Marks et al (2000).

For TRMM, once the GV data are properly quality controlled, the radar and gauge information are merged so that appropriate PMM and Z-R relationships can be determined. For TCSP, in calculating near-realtime error statistics, historically-derived multi-month Z_e-R PMM relationships will be used to convert radar reflectivities to rainrates.

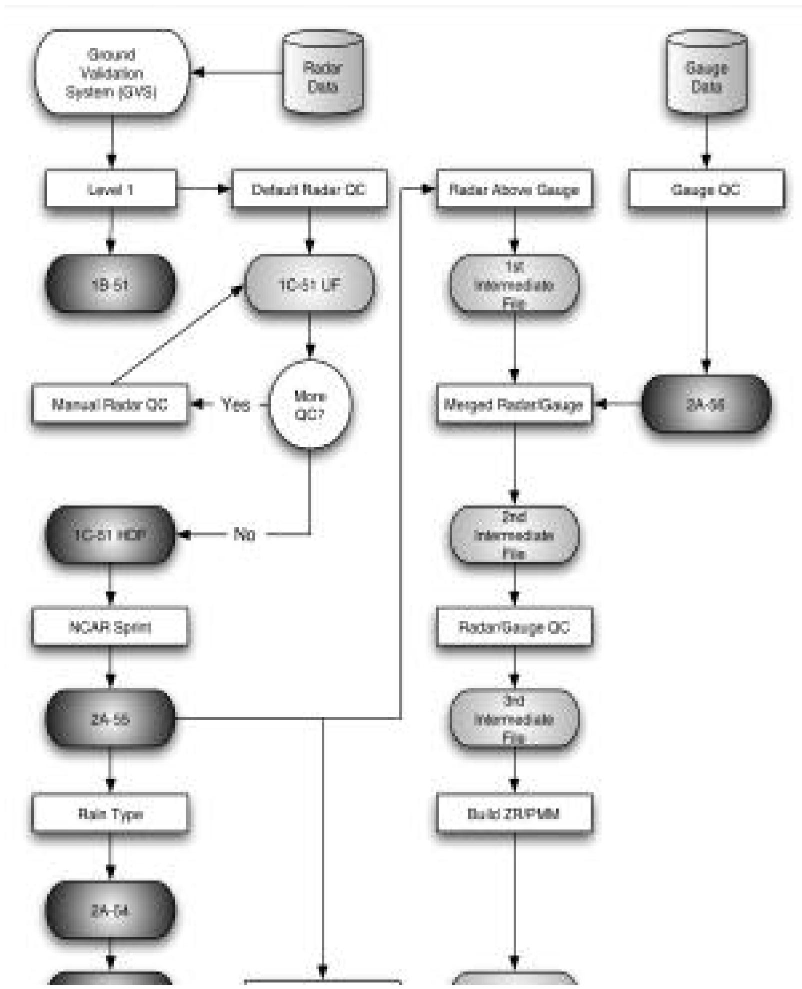

Figure 2: Flow diagram of Level 1 TRMM GV data processing. For purposes of study, only TRMM 2a53, 2a54 2a55, and 2a56 products are to be used.

Table 2: Description of Level II TRMM Science Data products to be used in study.

Product	Resolution	Description
2A-53	151 x 151 (2km x 2 km)	Rain intensity map (mm hr^{-1}) extending 150 km from the Melbourne WSR-88D radar.
2A-53	151 x 151 (2km x 2 km)	Rain type map (stratiform or convective) extending 150 from the Melbourne WSR-88D radar.
2A-53	151 x 151 x13 (2 km x 2 km x 1.5 km)	Three-dimensional gridded reflectivity extending horizontally 150 km from the radar. The first vertical level is at 1.5 km above the radar and extends to 19.5 km.

Catalonia-Spain Site

Whereas several overseas locations are under study by their associated organizations for developing international partnerships within the GPM GV Supersite network, the Catalonia group has already agreed to participate. The scientific reasoning behind their decision follows:

(1) Catalonia, Spain, indicated in Figure 3, is located in the Western Mediterranean (41^{o}N / 2^{o}E), with a mean annual rainfall of ~600 mm. The region's rainfall is characterized by frequent high rain intensity events, high spatial and temporal variability, and high impact of floods within populated areas. The return periods for events over 100 and 200 mm day^{-1} are six months and two years, respectively. The rainfall can be defined as continental, since most systems arrive from the west, being enhanced by mountain ridges within Catalonia and within the Spanish-French Pyrenees Range, prior to their movement to the east over the Mediterranean.

Catalonia maintains a network of four operational Doppler C-band radars with an inter-distance of 100 km, with plans to deploy a fifth in year 2005. One radar is owned by the Spanish National Weather Service (INM) and three by the Regional Weather Service of Catalonia (METEOCAT). The 4-member configuration provides a coverage-area of ~15,000 km^2 in which much of the coverage volume is always observed by at least 3 different radars at the same time (Figure 3). The region has a network of about 200 real time telemetric tipping bucket raingauges, with density of one gauge per ~130 km^2. A denser network operated by the Sewer System of Barcelona (www.clabsa.es) of 1 gauge per ~10 km^2 exists within the Barcelona metropolitan area. Operational flood warning, control system, and realtime rainfall-runoff forecasting models are available for the Besos Fluvial Park -- an area of ~1000 km^2 located to the northeast of Barcelona. Six-hourly radiosonde data are also available in realtime.

Plans for this meteorological observation system over the next five years include: (1) installation of the fifth C-band Doppler radar; (2) installation of a vertical profiler (UHF Doppler), and (3) creation of several super dense rain gauge networks (five rain gauges and one disdrometer per each of several 4 x 4 km^2 areas).

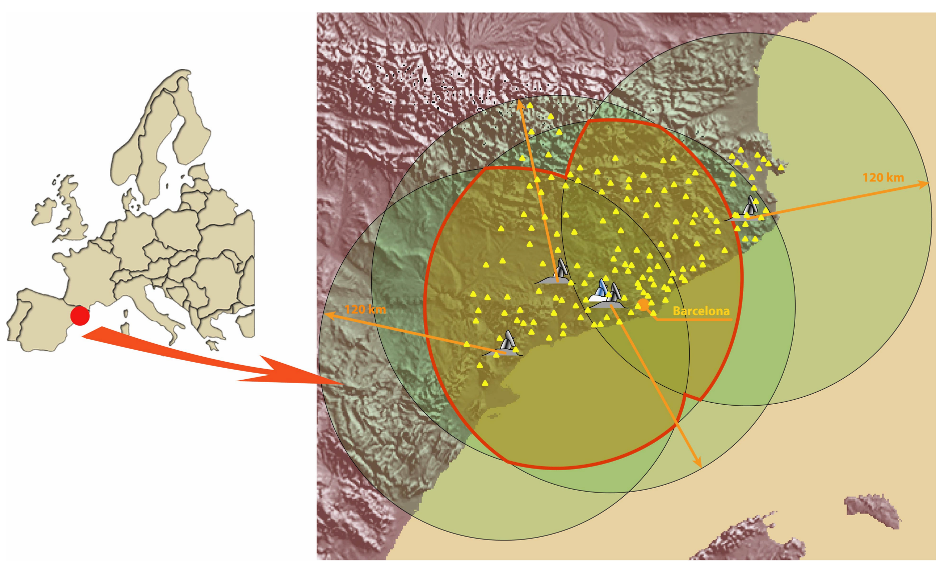

Figure 3: Location of Catalonia, Spain in western Mediterranean region, and METEOCAT/UPC-GRAHI C-band radar network.

Based on several years of strong collaboration between the Group of Applied Research in Hydrometeorology (GRAHI) (see www.grahi.upc.es) of the Universitat Politecnica de Catalunya (UPC), the Catalan Water Agency (ACA), and METEOCAT, composite rainfall field measurements from the three METEOCAT radars (both unadjusted adjusted to raingauge measurements), and raingauge data are now available in realtime operationally, and will be available to us at the METEOCAT server through arrangements between Dr. Smith (GPM Project Scientist), Prof. Daniel Sempere-Torres (Director of UPC-GRAHI), and Mr. Sergio Paricio (Assistant Director of METEOCAT). Volume scans and radar rainrate maps from each radar, and composite rainfall maps are all produced in near-real-time. The radar scans are every 6 minutes, while the raingauge temporal resolution depends on the network they belong (10-min accumulations for the 125 gauges of the ACA network and 30-min for gauges of other networks). The gauge data are available 30 min after collection time, and therefore the rainfall maps merged with raingauges are ready just beyond realtime. The data are received at METEOCAT in near-realtime via a microwave connection for radar and a radio connection for gauges. Data latency for the radar data is on the order of 10 min from the time of observation.

The data are archived routinely by a server and converted to metadata file format for distribution to approved parties. Data processing and quality control include: (1) lost azimuth correction; (2) stability control (Sempere-Torres et al. 2001, 2002); (3) orographic screening treatment (Delrieu and Creutin 1995); (4) ground clutter removal and substitution (Sánchez-Diezma et al. 2001a); (5) identification of rain type and application of a tailored Z-R relationship for each type (Sánchez-Diezma et al. 1998, 2000; Steiner et al. 1995). Once the data have been properly quality controlled, the radar and gauge data are merged so that an appropriate Z-R relationship can be determined more accurately. During 2004, UPC-GRAHI will devote substantial efforts in integrating the INM radar data into the existing composite of the three METEOCAT radars. In the next three years, UPC-GRAHI is also planning to develop the methodology of converting radar volume scans to 3D maps of reflectivity and, implementing this as an operation product at METEOCAT. Also, the 10-min accumulation gauge network of ACA is expected to have a shorter time delay than the current 30 min.

(2) Catalonia is involved in a European Commission Fifth Framework 2002-2005 precipitation validation project called VOLTAIRE (*Validation of Multisensors Precipitation Fields and Numerical \Modeling in Mediterranean Test Sit*e; www.voltaireproject.org). A foremost objective of VOLTAIRE is to design the GPM GV Supersite of Catalonia (Amitai et al. 2003a, Sempere-Torres et al. 2003), and to develop a hydrometeorological validation concept (Sánchez-Diezma et al. 2001b; Sempere-Torres and Amitai 2003). This project is aimed towards improved accuracy of surface-radar-derived precipitation fields based on experience gained from TRMM. VOLTAIRE is a multi-national project with collaboration of scientists from nine institutions, including two investigators involved with this proposal, i.e., Dr. Amitai of George Mason University, and Professor Sempere-Torres of UPC-GRAHI who has already been funded to collaborate with us on the GPM GV program under a separate project awarded by the Catalan Science Foundation.

(3) As noted, our proposed project is complemented by a parallel project, proposed by UPC-GRAHI and METEOCAT and now funded through the Catalan Science Foundation -- for developing the algorithms that will support the GPM-GV Supersite in Catalonia and the data communications protocol between METEOCAT/UPC-GRAHI and NASA/GSFC.

The Catalonia data information system for this study will acquire the simulated GPM satellite overpasses collected and archived in the same manner as for Central Florida at GSFC and the TCSP NPOL radar site in Costa Rica. Conversely, the Catalonia GV data will be transferred in near-real-time via high speed internet from METEOCAT in Barcelona to GSFC in Greenbelt. The GV data will contain the composite rainfall field from the radars, both unadjusted and adjusted to raingauge measurements. The horizontal resolution of the rainrate maps will be 2 x 2 km^2. The transferred products will consist of rainrate maps associated with all simulated satellite overpasses, and for some overpasses involving 3-D reflectivity products. The 3-D reflectivity products will be available during the second half of the project.

2.2 Description of Required Computer Facilities

Table 3 provides a list of computer and internet resources, and software minimally required for the present study. In the development and demonstration of GPM GV procedures, Interactive Data Language (IDL) will be used because of its versatility with data formats, built-in mathematical and statistical functions, and graphics capability. However, the same procedures will be available in FORTRAN for our partners who do not use IDL.

Table 3: Hardware and software requirements for proposed TCSP research project.

Item	**Cost**
IDL License Node locked license – Single User	$2600 w/3 year maintenance agreement
PC/Unix Workstation - RedHat Linux w/3 year license renewal - 3.4 GHz Intel 4 Processor - 2 GB RAM - 80 GB HD + 250 GB SATA HD - 128 MB Video Card - Keyboard/Mouse - 19" Monitor - CD/CD-RW/DVD Optical drive - 100 Base-T network card	$3500
Total	**$6,100**

2.3 Exploratory Research

There are two phases of the proposed research. The first is a build-up phase during which Florida and Catalonia GV radar data will be collocated with simulated GPM satellite data, and system procedures and software developed to calculate error characteristics of the satellite precipitation products. The second phase will develop the actual near-realtime capability of the GV system, testing of the system during the TCSP field phase, and a final live demonstration of the system at GSFC involving the two GPM GV sites.

The research plan for the first phase includes development of the following four procedures and techniques.

(1) Obtain computer hardware/software needed for GV system development and demonstration (section 2.2)

(2) Create data bank of satellite and GV products: Initially, data from 2003 and early 2004 will be used to develop GV procedures. For this period, hourly rainrates from NRL and 3-hourly rainrates from 3b42 over Central Florida and Catalunya will be acquired along with the appropriate radar rainrates from these sites. Non-zero rain events will be identified. Satellite rainrates will be interpolated to match ground radar resolution, with rainrates classified into convective and stratiform categories. This procedure will prepare pairs of convective and stratiform rainrate matrices from satellite and radar data.

(3) Develop error characterization technique, where error characterization will include following steps individually applied to convective and stratiform rainrates:

  (a) calculation of instantaneous spatial errors (systematic and random) between satellite and GV radar rainrates,
  (b) calculation of instantaneous spatial error covariance between satellite and GV radar rainrates: the instantaneous spatial error covariance, a 3-dimensional matrix, is generally defined as the difference between the autocovariance matrices between satellite rainrates and GV rainrates convolved to the requisite spatial resolutions,
  (c) calculation of space-time systematic and random errors and error covariance matrices: in order to generate integrated space-time error quantities, satellite and GV radar rainrates and instantaneous error quantities are accumulated on weekly time scale, and fully accumulated time scale (i.e., for duration of TCSP field campaign -- these data are then used to examine how instantaneous error quantities change with respect to different rain events, as well as their weekly and seasonal mean states,
  (d) checking for algorithm errors: once history of error quantities plus weekly / seasonal (experimental period) composite values are calculated, error estimates will be carefully checked for unusually large biases and/or unusual or abnormal instantaneous covariance structures, indicating likely problems with satellite retrievals and associated algorithm -- and during which a first version automated serious error flagging procedure will be devised,
  (e) exploratory research: various sensitivity studies will be carried out to refine and finalize space-time error characterization and serious error detection procedures.

(4) pdf comparisons: data bank containing GV and satellite overpass data will be used for demonstration of near-realtime error characterization (bias, bias uncertainty, error covariance structure) as described above. As required by GPM's GV system, developed procedures will include both identification and reporting of serious instantaneous retrieval errors to creators of rain rate algorithms significant error sources within standard Core S/CO level 2 rainrate algorithms, in order to motivate continuous algorithm improvement. Final GV system will allow improved understanding of underlying causes for algorithm breakdowns, which have affected quality of TRMM retrievals. In this context of algorithm improvement based on near-realtime GV measurements, further exploratory studies with respect to the central Florida and Catalonia cases will be needed, because the quality of the NASA NPOL radar data will fall short of the data already available from the GPM training sites.

A framework for physical validation and global verification of spaceborne radar estimates of rainrate is being developed. The framework demonstrates how a hydrologic approach that uses statistical properties of the precipitation to estimate the uncertainties can be combined with a meteorological approach that uses physical properties of the rainfall. The framework is based on comparing probability density functions (pdfs) from ground-based precipitation measurements and space-based precipitation estimates. The advantage of pdf comparisons is that they are free of the large uncertainties associated with pixel by pixel comparisons, e.g., satellite-induced temporal sampling uncertainty in accumulated rainfall. The framework also focuses on determining and reducing uncertainties in the ground validation pdfs based on adjusting ground-radar rainrate estimates with rainrates from a super dense raingauge network (Amitai et al. 2002; Amitai et al. 2004b).

Comparisons of pdfs from the TRMM PR and co-located WSR-88D radar data in Florida have already been studied (Amitai 2003, Amitai et al. 2003b, Amitai et al. 2004a-b). The framework includes the use of pdf comparisons before and after rain type classification. This allows for better evaluation of the satellite algorithms under different conditions, and for extrapolation of uncertainties to regions not covered by validation datasets, but characterized by the same rain type (meteorological regime). A suggested classification scheme is described in Amitai (1999) based on analyzing TRMM PR 3-D reflectivity field structure -- classified into fourteen (14) rain types, each characterized by a unique pdf of near surface reflectivities and mean rainrate.

An example of the comparison of pdf based on coincident TRMM PR and WSR-88D radar data is shown in Figure 4. A question could be asked concerning which curve better represents the truth. Uncertainties in the derived ground-based radar pdfs are likely to be smaller upon adjustment to the gauge-based rainrate distribution (V5) compared to those based on applying an adjusted power law (V4). Major differences between the PR and the GV pdfs remain after switching to V5. This is especially true at high rainrates, suggesting, in this example, over-correction of attenuation by the TRMM PR algorithm. Further analysis shows that only one or two overpasses dominated the trend observed here. In general, the PR pdfs are shifted toward low rainrate relative to the GV pdfs, i.e., the PR overestimates probabilities of low rainrate and conversely underestimates probabilities of high rainrate. Classification into the 14 rain types, using all overpasses over central Florida during 5 years of mission life (105 overpasses for rain events) indicates that the PR overestimates at high rainrate (i.e., the PR pdf is shifted toward high rainrate relative to the GV pdf) is found in only three of the rain types. In these rain types, the echo top heights usually exceed 9 km, always exceed 5 km, bright-band signature do not exist (i.e., highly convective cells), and horizontal gradients are weak. This supports the notion that partial beam filling is not necessarily at work, but that over-correction of attenuation is causing the error. This is also supported by the high mean rainrate compared to that of the GV for these classes. The latter analysis was recently performed in collaboration with UPC-GRAHI investigators (Amitai et al. 2004a).

Further development of this physical validation framework will be conducted during the course of this research. This includes further analysis based on pdf comparisons after rain type classification, and if available, utilizing the super-dense gauge network to better estimate the true pdf of rainrate. Finding the relevant rain types, which are characterized by pdfs that are stable in time and space, and defining for each type its uncertainties and other properties, such as mean rainrate, will allow for better evaluation of the satellite algorithms under different conditions. We will also assess the feasibility of characterizing errors and mean rainrate for a given domain (i.e., one overpass) based on counting pixels that contain a given rain type, and extrapolating uncertainties.

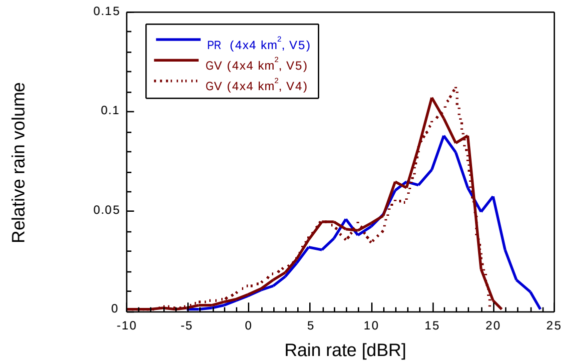

Figure 4: Distribution of rain volume as function of rainrate for Melbourne WSR-88D GV radar data and TRMM PR satellite retrieval data -- based on 24 overpasses during 1998, where GV data are within 100 km of Melbourne. GV rainrate estimates are from TRMM standard algorithm 2a53 (Version 4) based on power law and Version 5 based on PMM -- using 2 x 2 km^2 pixels averaged to 4 x 4 km^2 spatial resolution.

2.4 Demonstration of Near-realtime GV Capability

The ultimate goal of this study is to demonstrate how near-realtime satellite retrievals can be independently evaluated and assigned error characteristics, with the error information also being made available in near-realtime -- whether for the purpose of supporting the TCSP field campaign or supporting optimal rainfall data assimilation at experimental/operational forecast centers, i.e., the milieu of GPM. This will be an automated process that will prompt human operators at GV sites, and when implemented for the GPM Mission, to algorithm producers when satellite retrievals are found to exhibit seriously erroneous or unusual error characteristics. A live demonstration of the system will be given at GSFC during the last quarter of the final year of the project. The step-by-step procedure describing the near-realtime GV operation follows:

(1) Collect near-realtime satellite overpass data at GV site along with near-realtime ground radar and raingauge data.
(2) Select coordinates of non-zero rainrates
(3) Classify rainrates into convective and stratiform categories.
(4) Calculate instantaneous, systematic and random error quantities of satellite using radar rainrates as reference.
(5) Calculate instantaneous spatial covariance matrices of satellite rainrates (horizontal and vertical) using ground radar rainrates as reference for defining underlying spatial autocorrelation structure.
(6) Read out error quantities along with continuously accumulating time-averaged values.
(7) If instantaneous error quantities are larger than pre-defined threshold (TBD), then:
  (i) check satellite overpass data quality
  (ii) check GV radar data quality
  (iii) ascribe most probable satellite algorithm failure
  (iv) store satellite overpass and radar data, along with local wind components, temperature, humidity, and cloud conditions (from either local observations or operational analyses) for retrospective analysis

3.0 Expected Scientific Significance of Results

The most compelling aspect of this research, from a NASA research program perspective, is that it extends the meaning of ground validation for space-based retrievals into a near-realtime framework and in an proactive context. We have described in the proposal how this capability can be achieved for precipitation retrieval, however there is no good reason why these same ideas could not be applied to other types of space-based retrieval exercises where near-realtime GV reporting latency would represent added value to the full validation program. The general notion here is that ground validation should be considered as a dynamic process, in which the timeliness of the validation reporting increases the value of retrievals for near-realtime applications such as weather forecasting, rapid-response field campaigns, hydrometeorological predictions of surface water events (floods, droughts, accumulation of fresh water reserves, etc.), and in agrometeorology where probabilistic crop assessments requiring rain uncertainty factors are preferable to deterministic assessments for both market purposes and in downstream planning. The basic philosophy is that ground validation can be transformed from its more or less, post-mission detraction and a somewhat leisurely endeavor -- to a “seal-of-approval” and “time is of the essence” approach, where actual GV clients are being provided with valuable aids for use of the retrieval data.

In fact, the future success of the GPM Mission depends upon a near-realtime GV capability in the way of retrieval error characterization and in the filtering of serious individual error conditions -- as defined in mission requirements. These requirements are in response to the scientific community calling for error factors that enable optimizing rainfall data assimilation in NWP-based forecasts, and that would enable operating GPM-centric field campaigns in a manner in which intelligent scientific decisions could be made during A/C deployments, or for specialized point probe measuring -- where the question of the accuracy of precipitation retrieval itself is the topic of investigation. Therefore, we view the TCSP research program and the TCSP field campaign as an opportunity to develop the desired rapid-response GV capability, to test its scientific value, to begin to refine the ideas and applications behind dynamic validation, and to start paving the way for a required component of the GPM Mission.

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5.0 Management and Data Acquisition Plan

The Principal Investigator, Dr. Eric Smith, will be responsible for the overall organization, progress, success, reporting, and publication of the research. He will coordinate arrangements between METEOCAT/UPC-GRAHI and GSFC insofar as arranging for data acquisition from the Catalonian C-band radar network -- interfacing with Mr. Sergi Paricio, Assistant Director of METEOCAT, and with Professor Daniel Sempere-Torres of the UPC faculty and Director of the GRAHI Center. Dr. Smith will also coordinate arrangements with Dr. John Gerlach of the GSFC radar facility at Wallops Island, VA for acquisition of the NPOL and TOGA radar data in a dynamic GV mode, directly at the Central American radar facility.

Mr. David Wolff will be responsible for the complete design and much of the development of the hardware-software system needed to achieve the near-realtime GV capability, and for acquiring all necessary data from the Melbourne WSR-88D radar site, under near-realtime conditions, necessary to move the project forward immediately -- contingent upon its award. He will also be responsible for acquiring NPOL and TOGA radar data, with the proviso that these facilities are used for the TCSP field phase and the needed arrangements can be made with Dr. Gerlach, based on their close working relationship developed within the TRMM GV program, to obtain selected periods of NPOL data (and possibly TOGA data) on a near-realtime basis.

Dr. Amita Mehta will be responsible for all aspects of acquiring the near-realtime satellite precipitation data streams needed for the initial development phase (i.e., for both the Florida and Catalonia sites), and for the TCSP experiment domain, i.e., for the Pacific, Caribbean, and continental Central American sectors. She will also contribute to software development of the near-realtime GV system, as defined by Mr. Wolff.

Dr. Eyal Amitai, under a designated award to George Mason University (but included in the cost plan below), will be responsible for all aspects of data acquisition from the Catalonia radar network site, coordinating his activity with Mr. Xavier Llort at UPC-GRAHI, who will provide the software package for near-realtime data access to the METEOCAT radar data stream. Mr. Llort was responsible for developing much of this software under a UPC-GRAHI contract with METEOCAT. Dr. Amitai will also contribute to the software development of the near-realtime GV system, as defined by Mr. Wolff, and as discussed in section 2.3, will develop a framework for validating satellite rainfall estimates by using measurements from a super dense raingauge network to adjust coincident ground-radar rainrate retrievals through pdf analysis. This enables extending error characterization beyond the radar data acquisition boundaries, as discussed.

In evaluating the Section 7 cost plan, note that a portion of salary support for this research is being provided by the GPM Project for Drs. Smith and Mehta, as part of their assignments in developing GPM Mission elements, including GV capabilities, and from the TRMM Validation Project for Mr. Wolff, who leads the TRMM Validation Program, and is helping implement the transition from this program to the GPM Validation Program. Dr. Smith is requesting no funds for his participation whereas Dr. Amita and Mr. Wolff are balancing their contributions at a 1 to 1 ratio, i.e., each of their current assignments covers 0.2 FTE level of effort while the TCSP award covers the same. We are also re-cycling capital equipment from the TRMM Validation Program to provide needed computational facilities at the NPOL radar site in Costa Rica.

6.0 Investigator CVs

6.1 Dr. Eric A. Smith

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Email: eric.a.smith@nasa.gov; Website: http://gpmscience.gsfc.nasa.gov

Date of Birth: July 16, 1943 (SSN 391-42-3306)
Wife: Anna ('63); Children: Debra ('63), Richard ('64/deceased), Anakarin ('96), Alan ('97)

I . Education

1984: Ph.D., Atmospheric Science, Colorado State University, Fort Collins, CO
[*Radiative Forcing of the Southwest Summer Monsoon*]
1980: M.S., Atmospheric Science, Colorado State University, Fort Collins, CO
[*Orbital Mechanics and Analytic Modeling of Meteorological Satellite Orbits*]
1966: B.S., Mathematics & Comparative Literature, University of Wisconsin, Madison, WI

II. Professional Positions

2001-present: NASA Project Scientist for Global Precipitation Measurement (GPM) Mission, NASA/Goddard Space Flight Center, Greenbelt, MD.
1999-2000: Director & Chief Scientist, NASA/UAH Global Hydrology and Climate Center, Huntsville, AL (on 2-year leave from Florida State University).
1992-1994: Associate Chairman, Dept. of Meteorology, Florida State University, Tallahassee, FL.
1991-1994: Associate State Climatologist of Florida, Florida State University, Tallahassee, FL.
1989-2000: Professor, Dept. of Meteorology and Faculty Associate of Supercomputer Computations Research Institute, Florida State University, Tallahassee, FL. [Retired -- December 21, 2000]
1985-89: Associate Professor (Physical Meteorology), Dept. of Meteorology and Faculty Associate of Supercomputer Computations Research Institute, Florida State University, Tallahassee, FL.
1981: Assistant Professor (Cloud Physics and Radiation), Institute of Meteorology and Arid Land Studies, King Abdul-Aziz University, Jeddah, Saudi Arabia -- on leave from CSU on University of Arizona CID grant.
1979-84: Associate Research Scientist (Satellite Meteorology, Radiation and Climate), Dept. of Atmospheric Science, Colorado State University, Fort Collins, CO.
1975-79: Research Associate (Satellite Meteorology), Dept. of Atmospheric Science, Colorado State University, Fort Collins, CO.
1968-75: Project Specialist (Meteorological Satellite Data Analysis and Interactive Image Processing Systems Design), Space Science and Engineering Center, University of Wisconsin, Madison, WI.
1966-68: Project Specialist (Meteorological Satellite Data Analysis), Dept. of Meteorology & Space Science and Engineering Center, University of Wisconsin, Madison, WI.

III. Professional Affiliations, Honors, and Recent Activities

American Association for Advancement of Science; American Geophysical Union; American Meteorological Society; Institute of Electrical & Electronic Engineers; Sigma Xi.

Fellow of American Meteorological Society (1995); Chi Epsilon Pi; Dictionary of International Biography; Who's Who in American Education; Who's Who in the South and Southwest.

2003-Present: Principal Investigator, NASA Radiation Sciences Program.
1999-2003: Member, US-GCRP Water Cycle Study Group.
1999: Co-Chief Scientist for TRMM-KWAJEX field campaign on Kwajalein Atoll.
1999-2002: Principal Investigator and Science Team Member, NOAA-OGP GCIP.

1998-2002: Principal Investigator and Science Team Member, NSF-USWRP QPF Project.
1998-2002: Principal Investigator and Science Team Member, NASA LBA Experiment.
1997-1999: UCAR Steering Committee for Visiting Scientist Program at NCEP and NESDIS.
1997-2002: Principal Investigator, NASA Satellite Remote Sensing Measurement Accuracy, Variability, and Validation Studies.
1997-1999: Member, ARM Archive User Group.
1997-Present: Leader, TRMM TMI/PR Team.
1997-1999 Member, NASA EOSDIS Review Group (ERG).
1996-2002: Member, NASA Goddard Space Flight Center DAAC User Working Group.
1996-2001: Ex-Officio Member, AMS Committee on Satellite Meteorology and Oceanography.
1995-1999: Chairman, James R. Fisher Award Committee, FSU Chapter of Sigma Xi.
1994-1999: Editor, *Journal of the Atmospheric Sciences* (Physical Meteorology).
1994-Present: Member, Joint US-Japan TRMM Science Team.
1994-97: Leader, TRMM Combined Algorithm Team.
1994-96: Chairman, AMS Committee on Satellite Meteorology and Oceanography.
1993-2001: Principal Investigator and Science Team Member, NASA BOREAS Experiment.
1992-Present: Editor, *Meteorology and Atmospheric Physics*.
1991-Present: Principal Investigator and Science Team Member, US/NASA-Japan/NASDA TRMM Mission.
1988-97: Member, NASA Interactive-Network Science Team (WetNet).

IV. Biographical Sketch

Professor Smith is the NASA Project Scientist for the Global Precipitation Measurement (GPM) Mission within the Earth Sciences Directorate (Code 900) at the NASA/Goddard Space Flioght Center. His appointment is as senior scientist within the Laboratory for Atmosphere's (Code 910) Mesoscale Atmospheric Processes Branch (Code 912. He manages the scientific affairs of NASA vis-à-vis the GPM mission, coordinating GPM mission scientific activities with the space agencies of Japan (NASDA), Europe (ESA) and various other countries, as well as with a domestic and international set of research organizations. In addition, he conducts his own independent research program, made up of various research projects supported by the GPM mission and other NASA research programs, especially technology development programs. Beginning in the fall of 2003, Dr. Smith also will be affiliated with the University of Virginia's Dept. of Environmental Science as a part time research scientist and educator.

Prior to his current appointment, he was Director and Chief Scientist of the NASA/UAH Global Hydrology and Climate Center (GHCC) in Huntsville, Alabama, on a 2-year leave of absence from FSU. GHCC is a joint scientific institute comprised of the NASA/Marshall Space Flight Center (MSFC) Earth Science Directorate, the NASA/MSFC Global Hydrology Resource Center (GHRC), the University of Alabama at Huntsville (UAH) Department of Atmospheric Science (AS), and the University Space Research Association (USRA). While at GHCC, Dr. Smith taught a course in the UAH-AS program entitled "Remote Sensing of the Global Water Cycle". In December'00, at the time of his departure from GHCC after accepting a new position within NASAS at GSFC as the NASA GPM Mission Project Scientist, he retired from the faculty at Florida State University (FSU).

At FSU, Dr. Smith was a Professor in the Department of Meteorology and a Faculty Associate of the Supercomputer Computations Research Institute (SCRI). At FSU he taught in the physical program area of meteorology, focusing on the subjects of remote sensing of planetary atmospheres, atmospheric radiation processes and radiative transfer, dry-moist-saturation point thermodynamics, and atmospheric instrumentation. His research program focused on: (1) atmosphere-surface remote sensing studies including problems in optical, infrared, and microwave (passive & active) retrieval -- focusing on physical retrieval in both clear and cloudy atmospheres; (2) radiative energetics and hydrological processes within the Asian monsoon and a variety of desert heat low systems; (3) development and application of hydrometeorological process models involving radiative-heat-moisture transfer and carbon assimilation processes within vegetated canopies; and heat-moisture-momentum linkages between the land surface and planetary boundary layer using coupled hydrometeorological-mesodcale models. He was also the developer and manager of a real time GOES direct readout ground station facility.

From 1975 to 1984 he was a full-time research scientist at Colorado State University (CSU) conducting research in satellite meteorology and design of solid state image processing systems. His research at CSU included studies of cloud radiative properties; bi-spectral cloud retrieval techniques; multi-spectral analysis of visible infrared, and microwave data; estimation of cloud cover distribution and radiation budget parameters from weather satellite radiances; diurnal variation of tropospheric cloud-radiation processes within the tropics; earth radiation budget processes and solar variability; and satellite based precipitation estimation.

From 1966 to 1975, Dr. Smith was engaged in satellite related research at the University of Wisconsin's Space Science and Engineering Center. During this period he developed and published an interactive-correlative technique for estimating the wind field from time sequences of analytically navigated geosynchronous satellite images (WINDCO). This retrieval system has been widely applied in the framework of the Man-Computer Interactive Data Access System (McIDAS), of which he was one of the original developers and the first to publish. Its first important application was for the retrieval of the tropical wind field during the First GARP Global Experiment (FGGE) in 1979.

Dr. Smith received a B.S. in Mathematics at the University of Wisconsin in 1966, and the M.S. and Ph.D. degrees in Atmospheric Science at Colorado State University in 1980 and 1984, respectively. His Ph.D. dissertation focused on radiative exchange, radiative forcing, and cloud-radiation feedback within the Southwest Summer Monsoon at various space-time scales, incorporating a large data base of weather and experimental satellite observations for carrying out the diagnostic calculations.

Dr. Smith is a member and Fellow of the American Meteorological Society, the American Geophysical Union, the American Association for the Advancement of Science, the Institute of Electrical & Electronic Engineers, and the Society of Sigma Xi. He has served on a number of scientific committees and working groups involving the application of satellite observations in support of national and international research programs involving atmospheric and land surface studies. Much of this activity has been embodied within the Global Atmospheric Research Program (GARP) and World Climate Research Program (WCRP), and has included involvement with the GARP Atlantic Tropical Experiment (GATE), the First GARP Global Experiment (FGGE), the FGGE Summer Monsoon Experiment (SMONEX), the Agriculture and Resources Inventory Through Aerospace Remote Sensing (AgRISTARS), the Earth Radiation Budget Experiment (ERBE), the International Satellite Cloud Climatology Project (ISCCP), the India-United States Science and Technology Exchange Program (INDO-US S&T), the International Satellite Land Surface Climatology Project (ISLSCP), NASA's First ISLSCP Field Experiment (FIFE), NASA's Interdisciplinary Science Program (IDP), NASA's first Interactive-Network Science Team (WetNet), NASA's SSM/I Products Working Team (SPWT), NASA's Tropical Rainfall Measurement Mission (TRMM), the HAPEX-Sahel Experiment, the Boreal Ecosystem-Atmosphere Study (BOREAS), the Large-Scale Biosphere-Atmosphere Experiment in Amazônia (LBA), and the International Global Energy and Water Cycle Experiment (GEWEX) including the GEWEX Continental International Project (GCIP).

He has published over 300 papers, preprints, and technical reports, including over 150 refereed journal and book contribution publications dating from 1968. Research articles have appeared in over 20 journals including *Bull. Amer. Meteor. Soc., J. Appl. Meteor., J. Atmos. Sci., J. Climate, J. Clim. Appl. Meteor., Mon. Wea. Rev., J. Atmos. Oceanic Technol., Geophys. Res.-Atmospheres, J. Hydrol., IEEE Trans. on Computers, IEEE Trans. on Geoscience Electronics, IEEE Trans. on Geosciences and Remote Sensing, Meteor. Atmos. Phys., Climatic Change, J. Meteor. Soc. Japan, Canadian J. Rem. Sens., Rem. Sens. Reviews, Int. J. Remote Sensing, Adv. Space Res., and Solar Energy*. He has also given over 300 scientific lectures, seminars, and symposium papers at national and international scientific forums dating from 1971 including presentations in the United States, Canada, Europe, the Soviet Union, the Middle East, West Africa, Indonesia, Japan, Korea, Singapore, Taiwan, India, China, and Australia.

He has some 40 years of computer experience including developing large sets of software systems for satellite data and image processing, radiative transfer applications, and mathematical/statistical/modeling studies of remotely sensed data sets. This includes the design and development of interactive image display systems at the University of Wisconsin (McIDAS), Colorado State University (ADVISAR), and Florida State University (MIDGET; μVAX/IRIS 4D graphics system; SGI-based distributed graphics-processing network). He has had aircraft and ground based field experience both as a principal investigator and leader in a variety of settings including India, the Arabian Empty Quarter, the Gobi desert, the Rocky Mountains, the Tibetan Plateau, the Konza Prairie in Kansas, Sahelian West Africa, the Canadian Boreal Forest, the Amazon Rain Forest, the Western Pacific Ocean, and a number of areas in the State of Florida.

He has been a scientific reviewer for over 35 years for a variety of scientific journals and research funding agencies and has been a consultant to the World Meteorological Organization (WMO), the National Aeronautics and Space Administration (NASA), the European Space Agency (ESA), and various private institutions. He has been a principal investigator on research projects supported by a number of agencies including the National Science Foundation (NSF), the National Aeronautics and Space Administration (NASA), and the National Oceanic and Atmospheric Administration (NOAA).

V. Refereed Publications [from 1972 to present]

2004 Chandrasekar, C.V., E.A. Smith, V.N. Bringi, E. Gorgucci, T. Iguchi, M Masuko, R. Meneghini, S.A. Rutledge, and S. Yuter, 2004: Use of dual polarization radar in validation of satellite precipitation measurements: Rationale and opportunities. *Bull. Amer. Meteorol. Soc.*, in preparation.

2004 Grose, A.M.E., and E.A. Smith, H.J. Cooper, J. Gu, and J.D. Merritt, 2004: Modeling carbon sequestration over large scale Amazon basin aided by satellite observations. Part 3: Carbon exchange variability at multiple scales and scientific implications. *J. Clim.*, in preparation.

2004 Gu, J., and E.A. Smith, 2004: GOES satellite analysis of boreal forest snow albedo. *Remote Sens. Environ.*, in preparation.

2004 Im, E., E.A. Smith, S.L. Durden, Z. Haddad, R. Kakar, and C. Kummerow, 2004: The next generation of spaceborne rain radars: Science rationales and technology status. *Bull. Amer. Meteorol. Soc.*, in preparation.

2004 Lin , X., E.A. Smith, G. Asrar, W.J. Adams, J.P.V. Poiares Baptista, M. Byers, M. Cleave, M. Debois, J. Durning, D.F. Everett, Y. Furuhama, A. Ginati, T. Iguchi, P. Ingman, E. Im, C. Ishida, P. Joe, R. Kakar, D. Kendall, M. Kojima, C. Kummerow, V. Levizzani, A. Mugnai, K. Nakamura, S.P. Neek, R. Oki, G. Raju, D.A. Randall, S. Schneider, J.M. Shepherd, B.J. Sohn, J. Testud, G. Withee, and W.-J. Zhang, 2004: OSSE analysis of Global Precipitation Measurement (GPM) Mission's satellite constellation using GCM. *Bull. Amer. Meteorol. Soc.*, in preparation.

2004 Mehta, A., J. Susskind., and E.A. Smith, 2004: The TOVS Pathfinder Path A water vapor data set. *J. Geophys. Res.*, in preparation.

2004 Ou, M., and E.A. Smith, 2004: Short-range QPF over Korean peninsula using nonhydrostatic mesoscale model & "Future Time" data assimilation based on rainfall nowcasting from GMS satellite measurements. *Mon. Wea. Rev.*, in preparation.

2004 Santos, P., and E.A. Smith, 2004: Satellite retrieval of atmospheric water budget over Gulf of Mexico-Caribbean Sea basin. *J. Hydromet.*, in preparation.

2004 Shepherd, J.M., E.A. Smith, G. Asrar, and R. Kakar, 20004: Scientific case for international Global Precipitation Measurement (GPM) Mission. *Bull. Amer. Meteorol. Soc.*, in preparation.

2004 Smith, E.A., A.M.E. Grose, and H.J. Cooper, 2004: Modeling carbon sequestration over large scale Amazon basin aided by satellite observations. Part 2: Modeling framework and description of model. *J. Clim.*, in preparation.

2004 Smith, E.A., K-S. Kuo, and S. Yang, 2004: Analysis of history, intercomparison, and convergence of TRMM precipitation algorithms. *J. Appl. Meteorol.*, in preparation.

2004 Smith, E.A., G.J. Tripoli, S.T. Fiorino, V. Levizzani, A. Mugnai, G. Panegrossi, and F. Siccardi, 2004: Meteorology, macrophysics, microphysics, microwaves, & mesoscale modeling of Mediterranean mountain storms: An M^8 research laboratory. *Bull. Amer. Meteorol. Soc.*, in preparation.

2004 Smith, E.A., G. Asrar, A. Mehta, J.M. Shepherd, P. Bauer, R. Bras, V. Chandrasekar, D. Carson, H.J. Cooper, M. Debois, J. Entin, R. Ferraro, E. Foufoula-Georgiou, A. Ghazi, B. Goodison, Z. Haddad, A. Hou, P. Houser, T. Iguchi, E. Im, P. Joe, J. Kaye, K.-S. Kuo, C. Kummerow, W. Lau, D. Lettenmeir, V. Levizzani, G. Liu, N. Lu, F. Marks, V. Mehta, R. Meneghini, P. Morel, A. Mugnai, K. Nakamura, T. Nakazawa, K. Okamoto, R. Oki, G. Raju, F.R. Robertson, S. Rutledge, D.-B. Shin, G. Skofronik-Jackson, B.J. Sohn, S. Sorooshian, G. Stephens, E. Stocker, W.-K. Tao, J. Testud, G. Tripoli, F.J. Turk, J. Weinman, T. Wiheit, E. Wood, S. Yang, and S. Yuter, 2004: Global Precipitation Measurement (GPM) Mission: Past progress and future prospects. *Bull. Amer. Meteorol. Soc.*, in preparation.

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Workshop [4 – 7 November 2003; Abingdon, U.K.]. GPM Report Series #13, NASA/Goddard Space Flight Center, Greenbelt, MD, in preparation.
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2004 Turk, F.J., E.A. Smith, E. Amitai, E. Ebert, J. Hawkins, F.S. Marzano, A.Mehta, A. Mugnai, and B.J. Sohn, 2004: Blending coincident TRMM, SSM/I, AMSU, AMSR, and GEO-IR satellite data for rapid updates of global rainfall. *Bull. Amer. Meteorol. Soc.*, in preparation.

2004 Tao, W.-K., E.A. Smith, R. Adler, Z. Haddad, A. Hou, R. Kakar, T.N. Krishnamurti, C. Kummerow, S. Lang, R. Meneghini, W. Olson, S. Satoh, S. Shige, J. Simpson, Y. Takayabu, G. Tripoli, and S. Yang, 2004: Latent heating structures derived from TRMM satellite measurements. *Bull. Amer. Meteorol. Soc.*, submitted.
2004 Yang, S., and E.A. Smith, 2004: Mechanisms for diurnal variability of global tropical rainfall observed from TRMM. *J. Clim.*, submitted.
2004 Fiorino, S.T., and E.A. Smith, 2004: Critical assessment of microphysical assumptions within TRMM-radiometer rain profile algorithm using satellite, aircraft & surface datasets from KWAJEX. *J. Atmos. Sci.*, submitted.
2004 Haddad, Z.S., J.P. Meagher, R.F.Adler, E.A. Smith, E. Im, and S.L. Durden: El Niño and the variability of global precipitation. *J. Geophys. Res.*, submitted.
2004 Meagher. J.P., Z.S. Haddad, S.L. Durden, E. Im, and E.A. Smith: Drop size ambiguities in the retrieval of precipitation profiles from dual-frequency radar measurements. *J. Appl. Meteor.*, submitted.
2004 Tripoli, G.J., S. Pinori, S. Dietrich, G. Panegrossi, A. Mugnai, and E. Smith, 2004: The 9-10 November 2001 Algerian Flood: A numerical study? *Bull. Amer. Meteorol. Soc.*, submitted.
2004 Yuter, S.E., R.A. Houze Jr., E.A. Smith, T.T. Wilheit, and E. Zipser, 2004: An overview of the 1999 TRMM Kwajalein Experiment (KWAJEX). *J. Appl. Meteorl*., submitted.

2004 Smith, E.A., G. Asrar, Y. Furuhama, A. Ginati, R. Adler, V. Casse, M. Cleave, J. Durning, J. Entin, P. Houser, T Iguchi, R. Kakar, J. Kaye, M. Kojima, C. Kummerow, V. Levizzani, M. Luther, A. Mehta, P. Morel, A. Mugnai, K. Nakamura, T. Nakazawa, S. Neeck, R. Oki, G. Raju, M. Shepherd, J. Simpson, E. Stocker, and J. Testud, 2004: International Global Precipitation Measurement (GPM) Program and Mission: An overview. *Measuring Precipitation from Space: EURAINSAT and the Future* (V. Levizzani and F.J. Turk, eds.), Kluwer Publishers, in press.
2004 Mugnai, A., S. Di Michele, E.A. Smith, F. Baordo, P. Bauer, B. Bizzarri, P. Joe, C. Kidd, F.S. Marzano, A. Tassa, J. Testud, and G.J. Tripoli, 2004: Snowfall measurements by proposed European GPM mission. *Measuring Precipitation from Space: EURAINSAT and the Future* (V. Levizzani and F.J. Turk, eds.), Kluwer Publishers, in press.
2004 Dietrich, S., S. Di Michele, V. Kotroni, K. Lagouvardos, C. Medaglia, A. Mugnai, G. Panegrossi, E.A. Smith, and G.J. Tripoli, 2004: Comparing cloud microphysics and microwave signatures generated by different cloud resolving models? *Mediterranean Storms 2003* (edited by J. Testud), Proceedings of 5th EGS Plinius Conference on Mediterranean Storm (Ajaccio, Corsica; October 2003), in press.
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2004 Gamon, J., K.F. Huemmrich, D.R. Peddle, J. Chen, D. Fuentes, F.G. Hall, J.S. Kimball, S. Goetz, J. Gu, K.C. McDonald, J.R. Miller, M. Moghaddam, A.F. Rahman, J.-L. Roujean, E.A. Smith, C.L. Walthall, and P. Zarco-Tejada, B. Hu, R. Fernandes, and J. Cihlar, 2004: Remote sensing in BOREAS: Lessons learned. *Remote Sens. Environ.*, **89**, 139-162.

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2003 Sohn, B.J., E.S. Chung, J. Schmetz, and E.A. Smith, 2003: Estimating upper tropospheric water vapor from SSM/T2 measurements. *J. Appl. Meteor*., **42**, 488-504.

2002 Smith, E.A., and T.D. Hollis, 2002: Performance evaluation of level 2 TRMM rain profile algorithms by intercomparison and hypothesis testing. *Cloud Systems, Hurricanes, and the Tropical Rainfall Measuring Mission (TRMM): A Tribute to Dr. Joanne Simpson* (W.-K. Tao and R. Adler, eds., 234 pp), *AMS Meteorological Monographs*, **59**, 207-222.

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2002 Ruf, C., C. Principe, T. Dod, B. Monosmith, S. Musko, S. Rogacki, D. Steinfeld, E. Smith, A. Stewart, and Z. Zhang, 2002: Synthetic thinned aperture radiometer technology developments enabling a GPM lightweight rainfall radiometer. Proceedings of Earth Science Technology Conference 2002, NASA/Goddard Space Flight Center, Greenbelt, MD, 4 pp.

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1982 Smith, E.A., S.K. Cox, and T.H. Vonder Haar, 1982: Preliminary results from an Arabian heat low boundary layer experiment. Extended Abstract Vol., International Conf. on the Scientific Results of the Monsoon Experiment [Oct. 26-30; Denpasar, Bali, Indonesia], 1-7 to 1-12.

1982 Hickey, J.R., B.M. Alton, F.J. Griffin, H. Jacobowitz, P. Pellegrino, E.A. Smith, T.H. Vonder Haar, and R. Maschhoff, 1982: Solar variability indications from Nimbus 7 satellite data. Proceedings of Goddard Workshop on Solar Variability, NASA Report CP2191 [Nov., 1980; Greenbelt, MD], NASA-Goddard Space Flight Center, Greenbelt, MD, 59-72.

1982 Smith, E.A., and T.H. Vonder Haar, 1982: The nature of the short period fluctuations in solar irradiance observed by the Nimbus 7 satellite. Atmospheric Science Paper No. 342, Department of Atmospheric Science, Colorado State University, Fort Collins, CO, 22 pp.

1981 Vonder Haar, T.H., and E.A. Smith, 1981: Combined spaceborne and conventional measurements for precipitation estimation. Precipitation Measurements from Space, Workshop Report (D. Atlas and O.W. Thiele, editors) [April 28-May 1, 1980; Greenbelt, MD], NASA-Goddard Space Flight Center, Greenbelt, MD, D176 to D183.

1981 Smith, E.A., and J.R. Hickey, 1981: Solar variability analysis using Nimbus 7 ERB results. Results of Symposium, Fifth International Pyrheliometric Comparisons and Absolute Radiometer Comparisons (IPC-V), Working Report No. 194 - World Radiation Center [Sept. 29-Oct. 17, 1980; Davos, Switzerland], Published by Swiss Meteorological Institute, Zurich, Switzerland, 37-39.

1981 Hickey, J.R., F.J. Griffin, B.M. Alton, H. Jacobowitz, L.L. Stowe, P. Pellegrino, R.H. Maschhoff, F.B. House, E.A. Smith, and T.H. Vonder Haar, 1981: Review of solar irradiance measurements from Nimbus 6 and 7. Results of Symposium, Fifth International Pyrheliometric Comparisons and Absolute Radiometer Comparisons (IPC-V), Working Report No. 194 - World Radiation Center [Sept. 29-Oct. 17, 1980; Davos, Switzerland], Published by Swiss Meteorological Institute, Zurich, Switzerland, 17-20.

1981 Ackerman, S.A., E.A. Smith, and T.H. Vonder Haar, 1981: Regional radiative characteristics during the Southwest Summer Monsoon. Preprint Vol., International Conf. on Early Results of FGGE and Large-Scale Aspects of Its Monsoon Experiments [Jan. 12-17; Tallahassee, FL], Amer. Meteor. Soc., Boston, MA, 6:27-6:29.

1981 Smith, E.A., T.H. Vonder Haar, and J. Graffy, 1981: The impact of GOES satellite data compaction on the estimates of cloud parameters. Proceedings of the GISS Cloud/Climate Workshop - Clouds in Climate: Modeling and Satellite Observational Studies [Oct. 29-31, 1980; New York, NY], NASA-Goddard Institute of Space Studies, New York, NY, 192-196.

1981 Smith, E.A., 1981: Review of cloud climatologies. Proceedings of the GISS Cloud/Climate Workshop - Clouds in Climate: Modeling and Satellite Observational Studies [Oct. 29-31, 1980; New York, NY], NASA-Goddard Institute of Space Studies, New York, NY, 113-149.

1980 Campbell, G.G., and E.A. Smith, 1980: Cloud amount estimation from geosynchronous satellites: A demonstration of diurnal variation. Extended Abstract Vol., IAMAP International Radiation Symposium [August 11-16; Fort Collins, CO], Dept. of Atmospheric Science, Colo. State Univ., Fort Collins, CO, 312-314.

1980 Smith, E.A., 1980: The modulation by tropical cloud systems of the bulk radiation heat budget. Extended Abstract Vol., IAMAP International Radiation Symposium [August 11-16; Fort Collins, CO], Dept. of Atmospheric Science, Colo. State Univ., Fort Collins, CO, 352-354.

1980 Smith, E.A., and T.H. Vonder Haar, 1980: A first look at the summer MONEX GOES satellite data. Preprint for the American Inst. of Aeronautics and Astronautics, Fifteenth Thermophysics Conference [July 14-16; Snowmass, CO], AIAA, Washington, DC, 16 pp.

1979 Smith, E.A., and T.H. Vonder Haar, 1979: Fourth generation display systems and the multiple platform problem. Conference Record, Space Instrumentation for Atmospheric Observation - 1979 IEEE Region V Annual Conference [April 3-5; El Paso, TX], 74-78.

1978 Smith, E.A., and D.W. Reynolds, 1978: The generation and display of digital radar-satellite composites using analytic mapping techniques and solid state video refresh technology. AMS Conference on Weather

Forecasting and Analysis and Aviation Meteorology [Oct. 16-19; Silver Springs, MD], Amer. Meteor. Soc., Boston, MA, 8 pp.

1978 Loranger, D.C., E.A. Smith, and T.H. Vonder Haar, 1978: Initial estimates of GATE atmospheric radiation budgets with atmospheric heating considerations. Preprint Vol., Third AMS Conf. on Atmospheric Radiation [June 28-30; Davis, CA], Amer. Meteor. Soc., Boston, MA, 174-178.

1977 Smith, E.A., 1977: Digital imaging system used at Colorado State University. Workshop Proceedings - Interactive Video Displays for Atmospheric Studies [June 14-16; Madison, WI], Space Science and Engineering Center, University of Wisconsin, Madison, WI, 149-170.

1976 Reynolds, D.W., T.H. Vonder Haar, E.A. Smith, and D.W. Hillger, 1976: A bi-spectral method for cloud parameter determination. Abstract Vol., Nineteenth Meeting of COSPAR - Symposium on Meteorological Observations from Space: Their Contribution to the First GARP Global Experiment [June 8-10; Philadelphia, PA], COSPAR, Paris, France, 103-104.

1976 Smith, E.A., and D.W. Reynolds, 1976: Comparison of cloud top height determinations from three independent sources: Radar; satellite IR measurements; satellite viewed cloud shadows. Abstract Vol., Nineteenth Meeting of COSPAR - Symposium on Meteorological Observations from Space: Their Contribution to the First GARP Global Experiment [June 8-10; Philadelphia, PA]l, COSPAR, Paris, France, 103-104.

VII. Courses Taught

(1) Introduction to Meteorology (undergrad level; basic phenomona and processes of weather and climate); (2) Atmospheric Measurement (udergrad level; theory and operation of atmospheric instruments); (3) Atmospheric Physics I (undergrad/grad level; dry, moist, & saturation point thermodynamics); (4) Atmospheric Physics II (undergrad/grad level; atmospheric radiation and cloud physics); (5) Radative Transfer Modeling (grad level; solutions to RTE and numerical/parameterization techniques in clear, cloudy, and aerosol atmospheres); (6) Remote Sening of Planetary Atmospheres (grad level; principles and methodologies for remote sensing of terrestrial, inner, and outer planet atmospheres); (7) Microwave Remote Sensing of Hydrological Processes (grad level; theory and description of hydrological cycle and microwave remote sensing methods to measure global water cycle components)

VIII. Graduate Students Supervised

A. M.S. Students (12): William L. Crosson (1987), Lei Shi (1988), Donald R. Delorey (1989), Michael R. Farrar (1991), John Shattuck (1992), Michael Rubes (1993), Rosario Alfaro (1993), Gary Hodges (1997), David Faysash (1998), Throy Hollis (1999), Andrew Grose (2000), Edward Mansouri (2001)

B. Ph.D. Students (13): Kung-Whan Oh (1988), Byung-Ju Sohn (1990; awarded 3rd place for Best Ph.D. in Engineering, Mathematical, and Physical sciences for 1989-90 period – competition sponsored by University of Michigan's Ph.D. Dissertation Archives Institute, William L. Crosson (1991), Amita V. Mehta (1991), Lei Shi (1992), Patrick T. Welsh (1993), Mahendra Karki (1996), Song Yang (1996), Michael R. Farrar (1997), Steve Fiorino (2002), Pablo Santos (2003), Milim Oh (2003), Andrew Gross (2004)

IX. Research Funding Awards (Total 1974 to 2003: $15,471.9K)

2004	TBD	2003	2,265.0K
2002	2,730.0K	2001	810.0K
2000	584.5K	1999	731.2K
1998	711.5K	1997	572.0K
1996	459.2K	1995	460.8K
1994	623.2K	1993	485.5K
1992	532.8K	1991	655.5K
1990	434.2K	1989	509.5K
1988	257.5K	1987	175.5K
1986	194.0K	1985	93.0K
1975-84	2,142.0K	1974	45.0K

30. 2003-2005: Co-Principal Investigator (GSFC), IIP-NEXRAD In Space (NIS) – A Radar for Monitoring Hurricanes from Geostationary Orbit, NASA/Jet Propulsion Laboratory: [$560K allocation from ~$3,400K total award; 03/$200.0K] **$200.0K** to date.
29. 2002-2004: Principal Investigator (GSFC), IIP-Lightweight Rainfall Radiometer (LRR), NASA/Goddard Space Flight Center: [~$4,200K total award; 02/$1,500.0K, 03/$1,500] **$3,000.0K** to date.
28. 2001-present: NASA Project Scientist for NASA Global Precipitation Measurement (GPM) Mission (GSFC), NASA/Goddard Space Flight Center: [~$650,000K total mission budget with varying annual allocation to Office of Project Scientist: 01/$490.0K, 02/$1,000.0K, 03/$500K] **$1,990K** to date.
27. 1999-2001: Co-Principal Investigator (GHCC), IIP-2nd Generation Precipitation Radar (PR-2) Project, Jet Propulsion Laboratory: [$180K allocation from ~$4,000K total award; 99/$60.0K, 00/$60.0K, 01/$60.0K] **$180.0K** total.
26. 1999-2001: Principal Investigator (GHCC), Assimilating GOES-Derived LSTs into a Biosphere-Atmosphere Flux Exchange Model for Improved Prediction with a Nonhydrostatic Mesoscale Model, National Oceanographic and Atmospheric Administration: [99/$47.5K, 00/$49.5K, 01/$50.0K] **$147.0K** total.
25. 1999-2000: Principal Investigator (GHCC), IPA Support for GHCC Assignment, National Aeronautics and Space Administration: [99/$157.0K, 00/$165.0K] **$322.0K** total.
24. 1998-2002: Principal Investigator (FSU), Large Scale Carbon Budgets of Amazônia using GOES Satellite Measurements and Land Surface Model, National Aeronautics and Space Administration: [98/$68.1K, 99/$89.4K, 00/$95.0K, 01/$95.0K, 02/$115.0] **$347.5K** total.
23. 1998-2000: Principal Investigator (FSU), Improving Quantitative Precipitation Forecasts of Landfalling Atlantic Hurricanes using Satellite-Derived Hydrological Variables, National Science Foundation: [98/$90.0K, 99/$90.0K, 00/$90.0K] **$270.0K** total.
22. 1997-2000: Principal Investigator (FSU), FIFE/CaPE/HAPEX-Sahel Boundary Layer Circulations, National Aeronautics and Space Administration: [97/$60.0K, 98/$112.0K, 99/$118.0K] **$290.0K** total.
21. 1997-1999: Principal Investigator (FSU), Satellite-Derived Water Budget of Gulf of Mexico-Caribbean Sea Basin, National Aeronautics and Space Administration: [97/$160.0K, 98/$165.0K, 99/$170.0K] **$495.0K** total.
20. 1997-1999: Principal Investigator (FSU), Global Change Fellowship Program for David Faysash, National Aeronautics and Space Administration: [97/$22.0K, 98/$22.0K, 99/$22.0K] **$66.0K** total.

19. 1994-1996: Principal Investigator (FSU), Passive Microwave Retrieval Algorithm Development and WetNet Intercomparison Project, National Aeronautics and Space Administration: [94/$160.0K, 95/$130.0K, 96/$125.0K] **$415.0K** total.
18. 1993-1998: Principal Investigator (FSU), Canadian Boreal Forest Ecosystem-Atmosphere Study (BOREAS) Research, National Aeronautics and Space Administration: [93/$63.5K, 94/$96.3K, 95/$111.0K, 96/$107.2K, 97/$186.2K, 98/$79.4K, 99/$57.3K] **$700.9K** total.
17. 1992-1994: Principal Investigator (FSU), West Africa ISLSCP Experiment (HAPEX-Sahel) Research, National Aeronautics and Space Administration: [92/$52.0K, 93/$90.0K, 94/$90.0K] **$232.0K** total.
16. 1991-2003: Principal Investigator (FSU), Tropical Rainfall Measurement Mission (TRMM) Research, National Aeronautics and Space Administration: [91/$50.0K, 92/$129.8K, 93/$70.0K, 94/$105.0K, 95/$105.0K, 96/$112.0K, 97/$141.0K, 98/$175.0K, 99/$90.0K, 00/$115.0K, 01/$115.0K, 02/$115K, 03/65K] **$1,387.0K** total.
15. 1991-1994: Principal Investigator (FSU), Cape Canaveral Convection and Precipitation/Electrification Experiment (CaPE) Research, National Aeronautics and Space Administration: [91/$43.5K, 92/$55.0K, 93/$56.0K, 94/$59.9K] **$214.4K** total.
14. 1991: Principal Investigator (FSU), Ozone Measurements from Rocket Sondes at Cape San Blas, Florida Technological and Development Authority: [91/$100.0K] **$100.0K** total.
13. 1990-1993: Principal Investigator (FSU), Florida Space Grant Consortium:
    A. Undergraduate Space Research Participation (USRP): [90/$4.0K, 91/$4.0K, 92/$4.0K] **$12.0K** total.
    B. Space Research Assistantship Program (SAEP): [90/$8.0K] **$8.0K** total.
    C. Space Grant Fellowship Program (SGFP): [90/$12.0K, 91/$6.0K, 92/$12.0K] **$30.0K** total.
    D. Interinstitutional Space Research Program (ISRP): [91/$12.0K, 93/$12.0K] **$24.0K** total.
12. 1990: Principal Investigator (FSU), Council on Research and Creativity Grant (CRC), Florida State University: [90/$5.5K] **$5.5K** total.
11. 1989-1992: Principal Investigator (FSU), Interdisciplinary Studies Program (IDP) Research, National Aeronautics and Space Administration: [89/$42.5K, 90/$85.0K, 91/$95.0K, 92/$43.0K] **$265.5K** total.
10. 1989: Principal Investigator (FSU), GOES Direct Readout Ground Station Development, Florida Technological and Development Authority: [89/$75.0K] **$75.0K** total.
9. 1989: Principal Investigator (FSU), GOES Direct Readout Ground Station Development, College of Arts and Sciences, Florida State University: [89/$35.0K] **$35.0K** total.
8. 1987-1993: Principal Investigator (FSU), Collaborative Research Travel Grant Program, North Atlantic Treaty Organization: [87/$4.5K, 90/$6.2K, 92/$2.0K] **$12.7K** total..
7. 1987-1993: Principal Investigator (FSU), First ISLSCP Field Experiment (FIFE) Research, National Aeronautics and Space Administration: [87/$92.0K, 88/$65.0K, 89/$90.0K, 90/$71.5K, 91/$75.0K, 92/$75.0K, 93/$75.0K] **$543.5K** total.
6. 1986-1992: Principal Investigator (FSU), Microwave Modeling and Precipitation Retrieval Algorithm Research, National Aeronautics and Space Administration: [86/$10.0K, 87/$10K, 88/$106.0K, 89/$102.0K, 90/$115.0K, 91/$133.0K, 92/$160.0K] **$636.0K** total.
5. 1986-1989: Principal Investigator (FSU), Interdisciplinary Retrospective Studies Program (IRSP) Research, National Aeronautics and Space Administration: [86/$50.0K, 87/$63.0K, 88/$86.5K, 89/$40.0K] **$239.5K** total.
4. 1986: Principal Investigator (FSU), Graphics Workstation Development, Digital Equipment Corporation: [86/$41.0K] **$41.0K** total.
3. 1985-1997: Principal Investigator (FSU), Satellite-Radiation Studies of South West-East Asian Monsoon, National Science Foundation: [85/$93.0K, 86/$93.0K, 87/$6.0K, 89/$125.0K, 90/$127.0K, 91/$137.0K, 93/$119.0K, 94/$112.0K, 95/$114.8K, 96/$115.0K, 97/$2.8K] **$1,044.6K** total.
2. 1975-1984: Total from multiple sources while at Colorado State University [$2,142K].
1. 1974: Total from NASA while at University of Wisconsin [$45.0K].

X. Field Experience

1999: Principal Investigator and Co-Chief Scientist, TRMM Kwajalein Experiment (KWAJEX), August 14-September 5, Kwajalein Island, Republic of Marshall Islands.

1995: Principal Investigator Participant in Boreal Ecosystem-Atmospheric Study (BOREAS), July 17-August 4, Saskatchewan, Canada.

1994: Principal Investigator Participant in Boreal Ecosystem-Atmospheric Study (BOREAS), May 24-October 19, Saskatchewan and Manitoba, Canada.

1992: Principal Investigator Participant in HAPEX Sahel, August 17-October 9, Niamey, Niger.

1992: Principal Investigator Co-leader of Citrus Grove Moisture Budget Experiment (CIGMOBEX), January 15 - March 15, Gainesville, FL.

1991: Principal Investigator Participant in Convection and Precipitation-Electrification Experiment (CAPE), July 8-August 18, Cape Canaveral, FL.

1990: Principal Investigator and Co-leader of Surface Radiation and Energy Budget Experiment (SWAMP), September-November, Appalachicola National Forest, FL.

1989: Principal Investigator Participant (Surface Flux Measurement Team) of NASA's First ISLSCP Field Experiment (FIFE), July 17-August 15 (IFC-5), Konza Prairie, KS.

1988: Principal Investigator and Leader of Airsonde-Bowen Ratio Experiment, June-July,Tallahassee Regional Airport, Tallahassee, FL.

1987: Principal Investigator Participant (Surface Flux Measurement Team) of NASA's First ISLSCP Field Experiment (FIFE), May-October (IFCs 1-4), Konza Prairie, KS.

1986: Co-leader of Tibet Plateau Meteorology Experiment (TIPMEX-86), June-July, Tibet Plateau (Lhasa and Naqu), P.R.C.

1984: Principal Investigator Participant and Co-leader of Surface Radiation and Energy Budget Experiment, April-July, Gobi Desert, Western Gansu Province, P.R.C.

1983-1984: Co-principal Investigator and Leader of Surface Radiation and Energy Budget Experiment, May-June, Colorado Rocky Mountain Region (Pingree Park), Larimer County, CO.

1981: Principal Investigator and Leader of Surface Radiation and Energy Budget Experiment, May-June, Desert Empty Quarter (Rub al Khali, Sharuwrah), Saudi Arabia.

1979: Co-principal Investigator Participant in Bombay Phase of Summer Monsoon Experiment (SMONEX), May-June, Bombay, India.

6.2 Dr. Eyal Amitai

Current Position: Research Associate Professor, George Mason University.
Contact Address: NASA/GSFC/912.1, Greenbelt, MD 20771.
1-301-286-9224 (V); 1-301-286-1626 (F); Eyal.Amitai@gsfc.nasa.gov

Dr Amitai is a Research Associate Professor at the Center for Earth Observing and Space Research (CEOSR) within the School of Computational Sciences at George Mason University. Since 1990 he has been collaborating on the TRMM ground validation (GV) algorithms and spaceborne precipitation radar (PR) algorithms for accurate measurements of rainfall from Space. He is the lead scientist of the TRMM GV Climatological Processing and Product Development Group at NASA GSFC, and was a member of the NASA TRMM Science Team. He is a Principal Scientist in a European Commission Fifth Framework project for validation of multisensors precipitation fields and numerical modeling in Mediterranean test sites in preparation for the GPM mission (VOLTAIRE). He is currently also a PI of an NSF collaborative research entitled 'Spatial averaging of oceanic rainfall variability using underwater sound'.

Education:

1989-1996: Graduate Program, Department of Atmospheric Sciences, The Hebrew University of Jerusalem, Israel. Ph.D. degree: 1996; M.Sc. degree with distinction (Summa Cum Laude): 1991.

1985-1988: Under-Graduate Program, The Hebrew University of Jerusalem, Israel. B.Sc. degree with distinction (Cum Laude) in Atmospheric Sciences and Physics: 1989.

Scholarships and awards:

- The NASA Group Achievement Award to Fourth Convection and Moisture Experiment (CAMEX 4) Science Team. In recognition of outstanding accomplishments and contributions to the extremely successful CAMEX 4 conducted from Florida in Aug-Sept 2001.
- Recipient of the Wolf Foundation Scholarship for the most outstanding Ph.D. students in Israel for the academic year 1992/93.
- Dean's List for academic years: 1985/86, 1986/87, 1987/88.

Professional Positioins:

1/2003-present: Senior Research Scientist/ Research Associate Professor with the Center for Earth Observing and Space Research (CEOSR), School of Computational Sciences at George Mason University. Research is performed at the NASA/GSFC, Laboratory for Atmospheres, TRMM Satellite Validation Office.

8/1998-12/2002: Faculty position as Assistant Research Scientist with the Joint Center for Earth Systems Technology (JCET) at the University of Maryland Baltimore County (UMBC). Research performed at the NASA/GSFC, TRMM Satellite Validation Office.

5/1996-8/1998: Postdoctoral Research Scientist position with the Universities Space Research Association (USRA) at the NASA/GSFC for collaborating on the TRMM-PR algorithms.

10/1988-4/1996: Research Assistant and Teaching Assistant at the Institute of Earth Sciences, The Hebrew University of Jerusalem, Israel. Area of research: Radar Meteorology - quantitative measurement of rainfall with radar. Collaborating on the TRMM GV and PR algorithms: USRA Summer Visitor positions at NASA/GSFC (7/1990, 7-9/1992); USRA Temporary Consulting appointments (7-12/1994; 8-12/1995). Cloud Physics - the research included participation in cloud research flights over Israel and Thailand as part of cloud seeding experiments. Employed by Woodley Weather Consultants (Littleton, Colorado) through short term consulting appointments.

Relevant Peer Reviewed Publications:

- Amitai E., L. Liao, and X. Llort, 2004: Accuracy verification of spaceborne radar estimates of rain rate. *Atmospheric Sciences Letters* (submitted).
- Amitai E., E. Morin, M. Marcovina, and D. C. Goodrich, 2004: Sensitivity of the distribution of radar derived rain rates to different gauge adjustment techniques. *J. Appl. Meteor.* (submitted).
- Wolff D. B., D. A. Marks, E. Amitai, B. L. Fisher, D. S. Silberstein, A. Tokay, J. Wang, and J. L. Pippitt, 2004: Ground Validation for the Tropical Rainfall Measuring Mission (TRMM), *J. Atmos. Ocean. Technol.* (submitted).
- Amitai E., J. A. Nystuen, L. Liao, R. Meneghini, and E. Morin, 2004: Uniting space, ground and underwater measurements for improved estimates of rain rate. *IEEE Geoscience and Remote Sensing Letters*, Vol **1**, No. 2, 35-38.
- Nystuen, J. A., and E. Amitai, 2002: High temporal resolution of extreme rainfall rate variability and the acoustic classification of rainfall. *J. Geophys. Res.-Atmos.*, **108**(D8), 8378-8388.
- Amitai E., D. B. Wolff, D. A. Marks, and D. S. Silberstein, 2002: Radar rainfall estimation: Lessons learned from the NASA/TRMM validation program. *ERAD Publication Series*, **1**, 255-260 (Copernicus GmbH peer reviewed publication, ISBN 3-936586-04-7).
- Amitai E., D. B. Wolff, M. Robinson, D. A. Marks, M. S. Kulie, and B. S. Ferrier, 2001: Systematic variations of Z_e-R relations: Implications to Hydrology. *Remote Sensing and Hydrology 2000,* edited by M. Owe, K. Brubaker, J. Richtie and A. Rango, IAHS Publ. no. 267, 43-45, ISBN 1-901502-46-5).
- Amitai E., 2000: Systematic variation of observed radar reflectivity-rainfall rate relations in the tropics. *J. Appl. Meteor.* (TRMM Special Issue), **39**, 2198-2208.
- Robinson M., M. S. Kulie, D. Silberstein, D. A. Marks, D. B. Wolff, E. Amitai, B. S. Ferrier, B. L. Fisher, and J. Wang, 2000: Evolving Improvements to TRMM Ground Validation Rainfall Estimates. *Phys. Chem. Earth (B),* **25**, 971-976.
- Gabella M., and E. Amitai, 2000: Radar rainfall estimates in an alpine environment using different gage-adjustment techniques. *Phys. Chem. Earth (B),* **25**, 927-931.
- Atlas D., C. W. Ulbrich, F. D. Marks Jr., R. A. Black, E. Amitai, P. T. Willis, and C. E. Samsury, 2000: Partitioning tropical oceanic convective and stratiform rains by draft strength. *J. Geophys. Res.,* **105**, 2259-2267.
- Atlas D., C. W. Ulbrich, F. D. Marks Jr., E. Amitai, and C. Williams, 1999: Systematic variation of drop size and radar rainfall relations *J. Geophys. Res.*, **104**, 6155-6169.
- Amitai E., 1999: Relationships between radar properties at high elevations and surface rain rate: potential use for spaceborne rainfall measurements. *J. Appl. Meteor.,* **38**, 321-333.
- Rosenfeld D., and E. Amitai, 1998: Comparison of WPMM vs. regression for evaluating Z-R relationships. *J. Appl. Meteor.,* **37**, 1241-1249.
- Morin J., D. Rosenfeld, and E. Amitai, 1995: Radar rain field evaluation and possible use of its high temporal and spatial resolution for hydrological purposes. *J. Hydrology,* **172**, 275-292.
- Rosenfeld D., E. Amitai, and D.B. Wolff, 1995: Improved accuracy of radar WPMM estimated rainfall upon application of objective classification criteria. *J. Appl. Meteor.*, **34**, 212-223.
- Rosenfeld D., E. Amitai, and D. B. Wolff, 1995: Classification of rain regimes by the 3-dimensional properties of reflectivity fields. *J. Appl. Meteor.,* **34**, 198-211.
- Rosenfeld D., D. B. Wolff, and E. Amitai, 1994: The window probability matching method for rainfall measurements with radar. *J. Appl. Meteor.,* **33**, 682-693.
- Woodley W. L., E. Amitai, and D. Rosenfeld, 1994: Comparison of cloud tower and updraft radii with their internal temperature excesses relative to their environments. *J. Wea. Mod.,* **26**, 125-128.
- Rosenfeld D., D. Atlas, D. B. Wolff, and E. Amitai, 1992: Beamwidth effects on Z-R relations and area-integrated rainfall. *J. Appl. Meteor.,* **31**, 454-464.

Other Recent Relevant Publications

- Amitai E., L. Liao, X. Llort, and R. Meneghini, 2004: Accuracy Verification of Space and Ground-Based Radar Estimates of Rain Rate. Proceedings, *Sixth International Symposium on Hydrological Applications of Weather Radar*, February 2-4, Melbourne, Australia.
- Amitai E., J. A. Nystuen, and L. Liao, 2004: Listening to the rain. *Bull. AMS*, January 2004, p. 15.
- Amitai E., 2003: New NASA Radar-Gauge Adjusted Rain Fields and Comparison with TRMM. Proceedings, *VOLTAIRE* Workshop, October 6-8, Universitat Politecnica de Catalunya, Barcelona, Spain, ISBN 961-212-150-8. Available on line: http://www.voltaireproject.org/home_fr.htm (**Member of the Scientific Committee).
- Amitai E., J. A. Nystuen, and L. Liao, 2003: Uniting space, ground and underwater measurements for better estimation of rain rates. Preprints, *31st Int. Conf. Radar Meteorology*, August 6-12, Seattle, Washington, AMS 761-764.
- Amitai E., L. Liao, D. B. Wolff, D. A. Marks, and D. S. Silberstein, 2003: Challenges and proposed solutions for validation of rain rate estimates from space. *2003 IEEE Intl Geosciences and Remote Sensing Symp.*, Toulouse, France, Vol 3, 1966-1968 on ISBN CD-ROM: 0-7803-7930-6.
- Amitai E., 2003: Methodology and observational strategy for reducing uncertainties in rain rate estimates from space. *IUGG2003*, June 30-July 11, Sapporo, Japan.
- Amitai E., T. Einfalt, M. Gabella, U. Germann, S. Michaelides, G. Monacelli, G. Perona, D. Sempere-Torres, A. Speranza, and T. Vrhovec, 2003: VOLTAIRE: a 5th Framework Programme project for Validation of Precipitation Fields in Preparation for the GPM Mission. *ESA-NASA-NASDA 3rd Global Precipitation Measurement (GPM) Mission Workshop*, 24-26 June, ESTEC, Noordwijk, The Netherlands. Available on line from http://www.voltaireproject.org/home_fr.htm.
- Amitai E., E. Morin, and M. Marcovina, 2001: Sensitivity of the distribution of radar derived rain rates to different gauge adjustment techniques. Proceedings, *Fifth International Symposium on Hydrological Applications of Weather Radar*, November 19-22, Kyoto, Japan, 239-244 (**Member of the Int. Scientific Committee for the conference).
- Amitai E., D. B. Wolff, M. Robinson, D. S. Silberstein, D. A. Marks, M. S. Kulie, and B. Fisher, 2001: Methodologies for evaluating the accuracy of TRMM ground validation rainfall products. Preprints, *30th Int. Conf. on Radar Meteorology*, July 19-25, Munich, Germany, AMS 363-365 (**Chaired the session on TRMM).

Services of peer-review for numerous papers submitted to different leading journals in the field (e.g., Elsevier Science: Atmospheric Research; Taylor & Francis LTD: Int. J. Remote Sensing; The Royal Meteorological Society: Meteorological Application; American Meteorological Society: J. Atmos. Ocean. Technol., J. Appl. Meteor.; IEEE: Trans. on Geoscience and Remote Sensing; Canadian Meteorology and Oceanographic Society: Atmos.-Ocean.; American Geophysical Union: J. Geophys. Res. - Atmospheres, J. Geophys. Res. - Oceans. Water Resources Research; Wiley: Hydrological Processes; American Water Resources Association: J. American Water Resources Association), and for research proposals submitted to NASA (TRMM, CAMEX, and PMM NRAs) and NSF.

6.3 Dr. Amita Mehta

Current Position	Assistant Research Professor NASA-UMBC Joint Center for Earth Systems Technology (JCET)
Work Address	Code 912.1, NASA/Goddard Space Flight Center, Greenbelt, MD 20771 Phone: (301)-286-1446 Fax: (301)-286-1727 Email: amita@radar.gsfc.nasa.gov

Education

Ph.D., Meteorology	1991	Florida State University, USA
M.S., Meteorology	1987	Florida State University, USA
M.Sc., Physics	1982	Gujarat University, India
B.Sc., Physics	1980	Gujarat University, India

Professional Positions

Research Assistant Professor, JCET Goddard Laboratory for Atmospheres, NASA/Goddard Space Flight Center, Greenbelt, MD, USA	May 15, 2000 to present
Research Scientist, General Sciences Corporation Goddard Laboratory for Atmospheres, NASA/Goddard Space Flight Center, Greenbelt, MD, USA	Jul 1996 to May 2000
Research Scientist, USRA Goddard Laboratory for Atmospheres, NASA/Goddard Space Flight Center, Greenbelt, Md, USA	Jul 1991 to Jun 1996

Teaching Experience

Mentor of senior undergraduate and graduate student through NASA Summer Student Program during 1994, 1996, and 2002.

Instructor of a graduate course on ‘Atmospheric Dynamics’ in Department of Physics, University of Maryland Baltimore County during Fall semester 2002.

Grants

Title:	US-India Collaborative Research on Monsoon Predictability (Co. PI) (In collaboration with J. Shukla from Center for Ocean Land Atmosphere)
Agency:	NASA, 2001 - 2004
Title:	Unified Optical-Infrared-Microwave 3D Radiative Transfer Model for Coupling with Nonhydrostatic Mesoscale Model in Generating Predictions and Remote Sensing Simulations of Storm Life Cycles (Co. I.)
Agency:	NASA, 2003- 2006

Professional Activities

Referee for J. Geophysical Research, Geophysical Research Letter, J. Applied Meteorology, Meteorology and Atmospheric Physics.

Member of American Meteorological Society and American Geophysical Union.

Member of Global Precipitation Measurement (GPM) Science Working Group.

Publications

Mehta A. and J. Susskind, 1999: Outgoing longwave radiation from the TOVS Pathfinder Path A data set. *J. Geophys Res.*, **104**, 12193-12212.

Mehta A. and J. Susskind, 1999 : Longwave radiative flux calculations in the TOVS Pathfinder Path A data set. *NASA Tech. Rep.*, GSFC/CR1999-208643.

Otterman, D. Starr, T. Brakke, R. Davies, H. Jacobowitz, A. Mehta, F. Cheruy, and C. Prabhakara 1997 : Modeling Zenith-Angle Dependence of Out-going Longwave Radiation : Implication for Flux Measurements' *J. Remote Sens. Environ*., **62**, *90-100*.

Susskind, J., P. Piraino, L. Rokke, l. Iredell, and A. V. Mehta, 1997: Characteristics of the TOVS Pathfinder Path A Data Set. *Bull. of Amer. Meteorol. Soc.*, **78,** *1449-1472.*

Mehta, A. V. and E. A. Smith, 1997 : Variability of radiative cooling during Asian summer monsoon and its influence on intraseasonal waves. *J. Atmos. Sci*., **54,** *941-965***.**

Smith, E. A. and A. V. Mehta, 1990 : The role of organized tropical storms and cyclones on intraseasonal oscillations in the Asian monsoon domain based on INSAT satellite measurements. *Meteorl. Atmos. Phys*., **44,** *195-218***.**

Krishnamurti, T. N., D. Oosterhof, and A. V. Mehta, 1988 : Air-Sea interaction on the time scale of 30-50 days. *J. Atmos. Sci*., **45,** *1304-1319.*

Mehta, A. V. and T. N. Krishnamurti, 1988 : Interannual variability of the 30 to 50 day wave motions. *J. Met. Soc. Japan***, *66,*** *535-547*.

6.4 Mr. David B. Wolff

Served 16+ years with NASA Tropical Rainfall Measuring Mission (TRMM) Satellite Validation Office, currently as Program Manager. Lead effort to develop end-to-end data processing system for several TRMM GV sites. Also lead Data Analysis team that provides quality control, product development and distribution to TRMM Science Team and the general public through the TRMM Science Data and Information System (TSDIS) and the Goddard Space Flight Center (GSFC) Distribute Active Archive Center (DAAC).

AREAS OF EXPERTISE

Tropical meteorology
Radar rainfall estimation & rain gauge analysis
Satellite precipitation validation
Scientific software development
Network and computer system administration

EMPLOYMENT

Mar. 2000 to Present	SCIENCE SYSTEMS & APPLICATIONS, INC. *Program Manager*, TRMM Ground Validation Program Manager of TRMM Ground Validation group. Lead Product Evaluation Team responsible for providing error estimates on the TRMM GV products and developing and performing radar/satellite inter-comparisons, field campaign data analysis and delivery, and radar rainfall research. Also direct Software Development team tasked to provide data processing system necessary to produce TRMM Science Data Products. *Supervisor*: George Huffman, 301-614-6308
Jun 2002 to Present	CENTER FOR RESEARCH ON THE CHANGING EARTH SYSTEM *Information Technologist* Provide consulting and implementation of network infrastructure for non-profit scientific research organization. Provide administration of network (two separate T1 communication lines) and hardware (multiple PC/Linux/Mac). Provide consulting on development of “Virtual Center” for sharing data and ideas using web technology.
Sep 1997 to Mar 2000	STEVEN MYERS & ASSOCIATES *Project Manager*, TRMM Ground Validation TRMM GV group. Led teams responsible for software and system development for TRMM Ground Validation System (GVS). Also managed group responsible for quality control and standard data product processing of all TRMM GV data. Continued research in improved radar rainfall estimation techniques and quality control algorithms.
1988 to	APPLIED RESEARCH CORPORATION / SPACE APPLICATIONS CORP.

Sep 1997 *Task Leader*, TRMM Ground Validation Data Processing Team
Supervisor: William L. Ridgway, 301-286-9138

EDUCATION

MS Meteorology, Texas A&M University, 1988
BS Meteorology, Texas A&M University, 1986

PROFESSIONAL SOCIETIES AND OTHER INTERESTS

Squadron Commander, Sons of the American Legion, Post 105, Bethesda, Maryland . July 2000 – June 2001.
Member, American Meteorological Society, 1989-present
Member, American Geophysical Union, 2000-present
Member, Chi Epsilon Pi Honor Society, 1987, 1988
Treasurer, Texas A&M Meteorology Graduate Student Organization, 1987-88
Member, Scoring Committee, 1996, 1997 and 1999 U. S. Kemper Open Golf Tournament, Potomac, Maryland
Member, Greens Committee, 1997 U. S. Open Golf Tournament, Bethesda, Maryland.

FIELD PROGRAM EXPERIENCE

KAPP-II: Principal Investigator, Keys Area Precipitation Project - II: August-September, 2003, Florida Keys.
KAPP: Principal Investigator, Keys Area Precipitation Project: Aug. 1 - Oct. 9, 2002, Florida Keys.
KAMP: Keys Area Microphysics Project: Aug.-Sep. 2001, Florida Keys.
KWAJEX: Kwajalein Experiment, Aug-Sep 1999, Republic of the Marshall Islands
CAMEX-3: Convection and Moisture Experiment – III, Aug.-Sep, 1998, Florida
TEFLUN-A: TExas/FLorida UNderflight Experiment - A, Apr-May, 1998, Texas
TEFLUN-B: TExas/FLorida UNderflight Experiment - B, Aug-Sep, 1998, Florida
TEXACAL: Texas A&M Convection & Lightning Experiment, May-June, 1997, Texas
Visiting Scientist, Korean Meteorological Research Institute (KMRI), Seoul, Korea, October 1996
MCTEX: Maritime Continent Thunderstorm Experiment (MCTEX), Darwin, Australia, Nov-Dec 1995
Visiting Scientist, Thailand Royal Rain Making Institute, Chang Mai, Thailand, August, 1993
TOGA-COARE: Tropical Ocean/Global Atmosphere Coupled Ocean-Atmosphere Experiment, Nov 1992-Feb 1993, Western Pacific Warm Pool.
DUNDEE: Down-Under Doppler Electrification Experiment, Darwin, Australia, November, 1989.
TRMM Special Observing Period (SOP)-I, Darwin, Australia, Nov-Dec, 1989.
TRMM Special Observing Period (SOP)-II, Darwin, Australia, Nov-Dec, 1988.

REFEREED PUBLICATIONS

Amitai, E., D. B. Wolff, M. Robinson, D.A. Marks, M.S. Kulie, and B.S. Ferrier, 2000: Systematic variations of Ze-R relations: Implications to hydrology. *Remote Sensing and Hydrology, 2000,* IAHS Press, April 2000, Santa Fe, New Mexico.

Amitai E., D. B. Wolff, D. A. Marks, and D. S. Silberstein, 2002: Radar rainfall estimation: Lessons learned from the NASA/TRMM validation program. *Second European Conference on Radar Meteorology (ERAD),* November 18-22, Delft, The Netherlands. ERAD

Publication Series, **1**, 255-260 (Copernicus GmbH peer reviewed publication, ISBN 3-936586-04-7).
Atlas, David, Sergey Y. Matrosov, Andrew J. Heymsfield, Ming-Dah Chou, David B. Wolff, 2000: CORRIGENDUM. Journal of Applied Meteorology: Vol. 39, No. 12, pp. 2495–2495.
Atlas, D., S. Y. Matrosov, A. J. Heymsfield, M. D. Chou and D. B. Wolff, 1995: Radar and Radiation Properties of Ice Clouds. J. Appl. Meteor., **34**, No. 11, pp. 2329–2345.
Atlas, D., D. Rosenfeld and D. B. Wolff, 1993: On climatological C-band attenuation by rainfall using probability matched reflectivity-rainrate functions. J. Appl. Meteor., **32**, No. 2, 426-430.
Marks, D.A., M. S. Kulie, M. Robinson, D.S. Silberstein, D. B. Wolff, B. S. Ferrier, E. Amitai, B. Fisher, J. Wang, D. and O. Thiele , 2000: Climatological Processing and Product Development for the TRMM Ground Validation Program. Physics and Chemistry of the Earth, (PCE), Part B: Hydrology, Oceans and Atmosphere, **25**, 871-876.
Kedem, B., D. B. Wolff, and K. Fokianos, 2004: Statistical Comparison of Algorithms. *IEEE Trans. on Inst. and Msmt.*, **53**, 770-776.
Robinson M., M. S . Kulie, D. Silberstein, D. A. Marks, D. B. Wolff, E. Amitai, B. S. Ferrier, B. L. Fisher, and J. Wang, 2000: Evolving Improvements to TRMM Ground Validation Rainfall Estimates. Physics and Chemistry of the Earth (PCE), Part B: Hydrology, Oceans and Atmosphere, **25**, 971-976.
Rosenfeld, D., D. B. Wolff and E. Amitai, 1995: The Window Probability Matching Method (WPMM) for rainfall measurements with radar. J. Appl. Meteor., **33**, No. 6, 682-693.
Rosenfeld, D., E. Amitai and D. B. Wolff 1995: Classification of rain regimes by the 3-dimensional properties of reflectivity fields. J. Appl. Meteor, **34**, 198-211.
Rosenfeld, D., E. Amitai and D. B. Wolff 1995: Improved accuracy of radar WPMM estimated rainfall upon application of objective classification criteria with radar. J. Appl. Meteor., **34**, 212-223.
Rosenfeld, D., D. B. Wolff and D. Atlas, 1993: General probability matched relations between radar reflectivity and rain rate. J. Appl. Meteor., **31**, No. 5, 454-464.
Rosenfeld, D., D. Atlas and D. B. Wolff and E. Amitai, 1992: Beamwidth effects on Z-R relations and area integrated rainfall. J. Appl. Meteor., **32**, No. 1, 50-72.
Short, D. A., D. B. Wolff, D. Rosenfeld, and D. Atlas, 1993: A study of the threshold method utilizing rain gauge data. J. Appl. Meteor., **32,** No. 8, 1379-1387.
Wolff, D. B., 1988: The dependence of maximum realizable convective energy on horizontal scale in a one-dimensional entraining jet model. M. S. Thesis, Texas A&M University, 59 pp.

CONFERENCE PRESENTATIONS

Amitai, E., L. Liao, D. B. Wolff, D.A. Marks, D. S. Silberstein, 2003: Challenges and Proposed Solutions for Validation of Spaceborne Rain Rate Estimates. IGARSS 2003, Toulousse, France, July 21-25, 2003.

Amitai, E., D.B. Wolff, M. Robinson, D.S. Silberstein, D.A. Marks, M.S. Kulie, and B. Fisher Rainfall Product Evaluation for the TRMM Ground Validation Program. 2000. *AGU 2000 Fall Meeting*, San Francisco, CA December 2000.

Amitai, E., M. Robinson, D. B. Wolff, and D. S. Silberstein, 2000: Rainfall Product Evaluation for the TRMM GV Program. *TRMM Science Team Meeting*, October 2000, Greenbelt, Maryland.

Amitai, E., D. B. Wolff, M. Robinson, D.A. Marks, M.S. Kulie, and B.S. Ferrier, 2000: Systematic variations of Ze-R relations: Implications to hydrology. *Remote Sensing and Hydrology, 2000*, IAHS Press, April 2000, Santa Fe, New Mexico.

Amitai, E., D. Rosenfeld, and D. B. Wolff, 1995: Improved accuracy of radar WPMM estimated rainfall upon application of objective classification criteria. *Fourth Int'l Conference on Precipitation*. Iowa State University, Iowa City, Iowa, April 26-28, 1993.

Atlas, D., S. Y. Matrosov, A. J. Heymsfield, M. D. Chou and D. B. Wolff, 1995: Radar and Radiation Properties of Ice Clouds. Preprints, *Conference on Cloud Physics*, Amer. Meteor. Soc., Dallas, Jan 15-20, l995.

Atlas, D., D. Rosenfeld and D. B. Wolff, 1992: Climatic rainfall and attenuation measurements. Presented at the *Open Symposium of URSI Commission F*, Ravenscar, Yorkshire, U.K., June 8-12, l992.

Atlas, D., D. Rosenfeld, and D. B. Wolff, 1991: New approach to radar rainfall measurement. *7th Symposium on Meteorological Observations and Instrumentation.,* March, 1991. Paris, France.

Biggerstaff, M. I., J. Guynes, S. Veleva, E. K. Seo, K. Shelton-Mur, B. Karl, O. W. Thiele, J. C. Gerlach and D. B. Wolff. The Texas A&M University Convection and Lightning Experiment: TEXACAL 97. *28th Conference on Radar Meteorology*, Austin, Texas, Sept. 7-12, 1997.

Charalampidis D. , T. Kasparis, L. Jones, D. Wolff, M. Steiner, M. Robinson, 2002: A Quality Control Algorithm for the Removal of Non-Precipitation Echoes from Weather Radar Data. 1st International TRMM Conference, Honolulu, HI. July 21-26, 2002.

Cecil, D., D. B. Wolff, E. R. Toracinta and S. M. Nesbitt: 1998: Multi-sensor comparison of TRMM satellite and ground validation products from Texas and Florida squall line events. *19th Conference on Severe Local Storms*, Minneapolis, Minnesota, 14–18 September 1998.

Fisher, B. L., D. A., Short, D. B. Wolff, O. W. Thiele, 1997: The diurnal cycle of precipitation, temperature, and pressure over Melville and Bathurst Islands during MCTEX. *22nd Conf on Hurr. and Trop. Meteor.*, Ft. Collins, 370-371.

Fisher B., J. Wang, D. Wolff, 2002: The Effects of Temporal Sampling on TMI and PR Level 3 Rainfall Products: A Four-Year Validation Study over Oklahoma. *1st International TRMM Conference*, Honolulu, HI. July 21-26, 2002.

Fisher, B., D. Han, D. B. Wolff and O. W. Thiele, 1995: Precipitation measurements in Thailand and Asia as part of TRMM. *2nd International Study Conference on GEWEX in Asia and GAME*, Pattaya, Thailand

Kucera, P. A., D. A. Short, B. S. Ferrier, J. C. Gerlach, C. A. Leary, G. M. Jurica, S. H. Veleva, C. Demott, T. M. Richenbach, R. Cifelli, D. B. Wolff, R. C. Barritt, A. L. Doggett, O. W. Thiele, W. A. Petersen and S. A. Rutledge, 1995: COARE IOP rainfall measurements from shipborne radars: 2. Analysis and comparison of gridded fields. *27th Conference on Radar Meteorology*. Vail, Colorado. October 9-13, 1995.

Kulie, M. S., D. A. Marks, M. Robinson, D. S. Silberstein, D. B. Wolff, B. S. Ferrier, E. Amitai, B. Fisher, J. Wang, D. Augustine, and O. Thiele,. Climatological processing of Radar Data for the TRMM Ground Validation Program. AGU Washington, DC, June 2000

Kulie, M. S., M. Robinson, D. A. Marks, B. S. Ferrier, D. Rosenfeld, and D. B. Wolff, 1999: Operational processing of ground validation data for the Tropical Rainfall Measuring Mission, Preprints, 29th International Conference on Radar Meteorology, Montreal, Canada, July, 12-16, Montreal, Canada, AMS, 736-739.

Marks D., D. Silberstein, D. Wolff, E. Amitai, B. Fisher, J. Wang, B. Kelley, R. Lawrence, 2002: Improvements and Validation Techniques for TRMM Ground Validation Products. *1st International TRMM Conference*, Honolulu, HI. July 21-26, 2002.

Robinson, M., M. Steiner, D. B. Wolff, B. S. Ferrier Fisher, B. L., D. A. Short, D. B. Wolff, and O. W. Thiele: The diurnal cycle of precipitation, temperature and pressure over Melville and Bathurst Islands during MCTEX. *22nd Conference on Hurricanes and Tropical Meteorology*, Ft. Collins, Colorado, May 18-23, 1997.

Robinson, M., M. Steiner, D. B. Wolff, B. S. Ferrier, and C. Kessinger, 2000: Evaluation of various radar data quality control algorithms based on accumulated radar rainfall statistics. *American Geophysical Union Meeting,* May 2000, Washington, D. C.

Short, D. A., D. B. Wolff, D. Rosenfeld, and D. Atlas, 1989: A rain gage, radar and satellite simulation study of the estimation of convective rainfall by area-time integrals. *Fourth Conference on Satellite Meteorology and Oceanography.* American Meteorological Society, San Diego, CA, May 16-19, 1989.

Short, D. A., O. W. Thiele, D. B. Wolff, and K. J. Kowalewsky, 1989: Area-time integral relations in tropical rain: application to satellite rainrate retrievals. *1989 Spring Meeting of the American Geophysical Union*. AGU, Baltimore, MD, May 7-12, 1989.

Stewart, S. R., J. Simpson and D. B. Wolff: Convectively-induced mesocyclonic vortices in the eyewall of tropical cyclones as seen by WSR-88D Doppler radars. *22nd Conference on Hurricanes and Tropical Meteorology,* Ft. Collins, Colorado, May 18-23, 1997.

Steiner, M., M. Robinson, C. Kessinger, D. B. Wolff, 2000: An intercomparison of radar data quality control algorithms based on radar rainfall statistics. *TRMM Science Team Meeting*, October 2000, Greenbelt, Maryland.

Tokay A., D. Wolff, B. Fisher, K. R. Wolff, P. Bashor, J. Wang, D. Marks, D. Silberstein, B. Kelley, D. Makofski, D. Augustine, M. Marcovina, J. Wood, E. Amitai, R. Lawrence, 2002: Surface Rainfall Measurements during the Keys Area Microphysics Project (KAMP): An Overview, 2002: *1st International TRMM Conference*, Honolulu, HI. July 21-26, 2002.

Thiele, O. W., D. A. Short, J. C. Gerlach, D. B. Wolff, M. J. McPhaden and J. C. Wilkerson, 1994: TOGA-COARE Ocean precipitation morphology. *Sixth Conference on Climate Variations*, Nashville, Tennessee, January 23-28, 1994.

Williams, E., D. Rosenfeld, N. Madden, J. Gerlach, N. Geears, L. Atkinson, N. Dunnemann, G. Frostrom, M. Antonio, B. Biazon, R. Camarog, H. Franca, A. Gomes, M. Lima, R. Machado, S. Manhaes, L Nachtigall, H. Piva, W. Quintiliano, L. Machado, P. Artaxo, G. Roberts, N. Renno, R. Blakeslee, J. Bailey, D. Bocippio, A. Betts, D. Wolff, B. Roy, J. Halverson, T. Rickenback, J. Fuentes, and E. Avelino: 2003: Contrasting convective regimes over the Amazon: Implications for cloud electrification. *Jou. Geo. Res.*, Vol. 107, No. D20.

Wang J., D. B. Wolff, 2002: Comparison of Radar Reflectivity from TRMM Satellite and Ground Validation, 2002: *1st International TRMM Conference,* Honolulu, HI. July 21-26, 2002.

Wolff, D. B., E. Amitai, D. A. Marks, D. S. Silberstein, and A. Tokay, 2003: Validation for the Tropical Rainfall Measuring Mission and Evolution Towards a Global Precipitation Mission. *3rd GPM Workshop*, Nordwijk, The Netherlands, Jun 24-26, 2003.

Wolff D. B., E. Amitai, A. Tokay, D. Marks, B. Fisher, D. Silberstein, J. Wang, K. R. Wolff, D. Augustine, D. Makofski, 2002: Status and Future Plans for the TRMM Ground Validaton Program, *1st International TRMM Conference,* Honolulu, HI. July 21-26, 2002.

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Wolff, D. B., R. E. Orville, and E. L. Zipser, 1999: Inter-comparison of ground- based radar reflectivity, NLDN lightning data, and TRMM/TMI brightness temperatures and precipitation radar data.. *11th International Conference on Atmospheric Electricity*, Guntersville,. Alabama. Jun. 7-11, 1999.

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Wolff, D. B., D. A. Short, B. L. Fisher and O. W. Thiele. Radar analysis of coastal hurricanes using WSR-88D radar data. *28th Conference on Radar Meteorology*, Austin, Texas, Sept. 7-12, 1997.

Wolff, D. B., B. L. Fisher, O. W. Thiele and D. Han, 1995: Diurnal cycle of tropical rainfall based on rain gauge data: Implications for Satellite Rainfall Retrievals. *27th Conference on Radar Meteorology*. Vail, Colorado. October 9-13, 1995.

Wolff, D. B., O. W. Thiele and D. Han, 1995: Use of WSR88D radar data as part of the Tropical Rainfall Measuring Mission's Global Validation program. *Second WSR-88D Level II Data User Workshop.* May 16-18. Asheville, North Carolina.

Wolff, D. B., O. W. Thiele and D. Han, 1995: A ground validation radar data processing system for the Tropical Rainfall Measuring Mission(TRMM). *27th Conference on Radar Meteorology*. October 9-13. Vail, Colorado

Wolff, D. B., O. W. Thiele, D. Rosenfeld, B. L. Fisher and D. A. Short, 1993: TRMM Ground Truth surface rainfall estimates for Darwin, Australia. *Fourth Int'l Conf. on Precipitation*. Iowa State University, Iowa City, Iowa, April 26-28, 1993.

Wolff, D. B., D. Atlas and D. Rosenfeld, 1991: Correcting rainfall measurements for attenuation by use of probability matched Z_e-R functions. *Symposium on Retrieval of Precipitation Rates from Satellites.* Texas A&M University, College Station, Texas, February 20-22, 1991.

JOURNALS REFEREED

Journal of Applied Meteorology
Journal of Atmospheric and Oceanic Technology
Monthly Weather Review

REFERENCES

1. Dr. David Atlas, Distinguished Visiting Scientist, NASA Goddard Space Flight Center. (301-286-6292)
2. Dr. Daniel Rosenfeld, Head, Laboratory for Rain and Cloud Physics, Institute of Earth Sciences, The Hebrew University of Jerusalem, Jerusalem 91904 Israel. (972-2-585-821)
3. Richard Lawrence, Chief, TRMM Satellite Validation Office, NASA/GSFC. (301-286-2119)

7.0 Cost Plan

Overall Cost Summary

	Year 1	Year 2	Year 3	Total
NASA/GSFC Component	$94.6	$91.5	$94.9	$281.0
George Mason Univ. Component	61.9	64.9	68.0	194.8
GRAND TOTAL	156.5	156.4	162.9	**475.8**